

SEDIMENT TRANSPORT IN THE LOWER YAMPA RIVER,  
NORTHWESTERN COLORADO

By John G. Elliott, James E. Kircher, and Paul Von Guerard

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U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 84-4141

Prepared in cooperation with the  
NATIONAL PARK SERVICE

Lakewood, Colorado  
1984

UNITED STATES DEPARTMENT OF THE INTERIOR

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## CONVERSION TABLE

The inch-pound units used in this report may be converted to SI (International System of Units) by use of the following conversion factors:

<i>Multiply inch-pound unit</i>	<i>By</i>	<i>To obtain SI unit</i>
acre foot (acre-ft)	0.001233	cubic hectometer
acre foot per year (acre-ft/yr)	0.001233	cubic hectometer per year
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per foot (ft/ft)	1.000	meter per meter
inch (in.)	25.40	millimeter (mm)
inch per year (in./yr)	25.40	millimeter per year
mile (mi)	1.609	kilometer
square foot (ft <sup>2</sup> )	0.0929	square meter
square mile (mi <sup>2</sup> )	2.590	square kilometer
ton (short)	0.9072	metric ton
ton per day (ton/d)	0.9072	metric ton per day
ton per year (ton/yr)	0.9072	metric ton per year

To convert degrees Celsius (°C) to degrees Fahrenheit (°F) use the following formula:  $(^{\circ}\text{C} \times 9/5) + 32 = ^{\circ}\text{F}$ .

Suspended-sediment concentrations are given only in milligrams per liter (mg/L) because these values are (within the range of values presented) numerically equal to concentrations expressed in parts per million.

## LIST OF SYMBOLS

- $A_f$  = Cross sectional area of flow (ft<sup>2</sup>)
- $\bar{D}$  = Mean depth of flow (ft)
- $Q$  = Instantaneous water discharge (ft<sup>3</sup>/s)
- $Q_s$  = Sediment discharge (tons/day)
- $R$  = Correlation coefficient
- $R^2$  = Coefficient of determination
- $SE$  = Standard error of estimate
- $W$  = Channel width (ft)
- $d_{50}$  = Median particle grain size (mm)
- $n$  = Sample size
- $\bar{u}$  = Mean velocity of flow (ft/s)

## SEDIMENT TRANSPORT IN THE LOWER YAMPA RIVER, NORTHWESTERN COLORADO

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### ABSTRACT

Discharge measurements and sediment samples were taken at streamflow-gaging station 09260050 Yampa River at Deerlodge Park in 1982 and 1983 to determine the average annual sediment supply to the Yampa Canyon in Dinosaur National Monument. Daily mean discharge recorded at the Deerlodge Park gage correlated well with the sum of daily mean discharges recorded at two streamflow-gaging stations in the drainage basin upstream: Station 09251000 Yampa River near Maybell, and station 09260000 Little Snake River near Lily. Because of good correlation of discharges recorded during the study period ( $R^2=0.98$ ), 43 years of discharge records at the two tributary sites were combined to determine the historic discharge of the Yampa River at Deerlodge Park. An historic average hydrograph and a flow-duration curve were derived from the combined discharge data.

Sediment-transport equations were derived for total sediment discharge, suspended-sediment discharge, bedload discharge, and the discharge of sediment in several particle-size ranges. Annual sediment discharges were determined by the flow-duration, sediment-rating-curve method. These computations indicated that mean annual total sediment discharge was approximately 2.0 million tons per year of which 0.8 million tons per year was sand-size material. Bedload was almost entirely sand, and mean annual bedload discharge was 0.1 million tons per year.

Development of water resources in the Yampa River basin could have considerable effect on the geomorphic and biological character of the Yampa River at Deerlodge Park and through the Yampa Canyon. In this report, several scenarios of altered streamflow frequency distribution, reduced streamflow volume, and reduced sediment supply are examined to estimate the effect on the sediment budget at Deerlodge Park.

### INTRODUCTION

Channel morphology as well as the aquatic and riparian habitat of the Yampa River in Dinosaur National Monument is primarily controlled by the prevailing streamflow regime and transported sediment. The river channel will adjust to significant long-term changes in the total volume of annual streamflow, the range of discharge, the sediment supply, or the particle size of sediment. Water resource development in the Yampa River basin could lead

to substantial alteration of the Yampa River through Dinosaur National Monument. This study was undertaken to determine the prevailing conditions of streamflow and sediment discharge through Deerlodge Park, and to estimate the effect of changes in hydrology or sediment supply on the sediment budget.

The Yampa River drains approximately 8,000 mi<sup>2</sup> in northwestern Colorado and south-central Wyoming, and is a major component of the upper Colorado River system (fig. 1). The Little Snake River, a principal tributary, drains approximately 3,730 mi<sup>2</sup> and joins the Yampa River in Deerlodge Park. Mean-annual runoff from the Yampa River basin is approximately 1.5 million acre-ft/yr. Altitudes in the watershed range from 5,065 ft at the river's mouth to over 12,000 ft in the headwaters in the Park Range. Precipitation varies from less than 12 in./yr in the western part of the basin to over 60 in./yr at higher altitudes along the Continental Divide. Most of the precipitation falls on the basin as snow from November through April, although intense localized thunderstorms occur during the summer months.

Tertiary and Cretaceous sandstones, mudstones, and shales underlie most of the basin (Tweto, 1979) and are the source of most of the material transported by the Yampa River in its lower reaches. The Yampa River is entrenched into Permian and Pennsylvanian sandstones and limestones of the Uinta Mountain uplift for the last 45 mi of its course; little of the transported sediment is derived from these formations.

Immediately upstream from the Yampa River Canyon is Deerlodge Park, a broad valley where the Little Snake River joins the Yampa River. The Yampa River Canyon was formed in the Uinta Mountain uplift (Hunt, 1969), and it lies within the boundaries of Dinosaur National Monument. Entering the canyon, the river gradient steepens and the channel is entrenched in bedrock. Riverbanks are predominantly bedrock or talus material. Sand, gravel, and cobbles are found locally in bars or along banks where the river gradient lessens, or where the canyon width increases. Mobile sediments periodically are scoured from the bed and banks and redeposited as floodflows pass through the canyon.

The canyon of the lower Yampa River in Dinosaur National Monument is a unique feature in the Western United States. With no major dams, and modest water consumption (approximately 10 percent of annual streamflow, Steele and others, 1979), the Yampa River, in its lower reaches, retains a relatively pristine character. As such, the Yampa River in Dinosaur National Monument offers the visitor a rare opportunity to observe and study the biological and geomorphological setting of a relatively undisturbed river system. Annual streamflow in the Yampa River has been measured and sediment yields estimated for prevailing conditions; however, the effects of changes in either of these two variables previously have not been addressed. The objectives of this investigation are:

1. To establish the relation between sediment discharge and water discharge for the Yampa River above the entrance to Yampa Canyon at Deerlodge Park.
2. To determine the mean annual hydrograph and flow-duration relation for the prevailing streamflow at Deerlodge Park.
3. To compute the mean annual sediment supply to the Deerlodge Park reach.

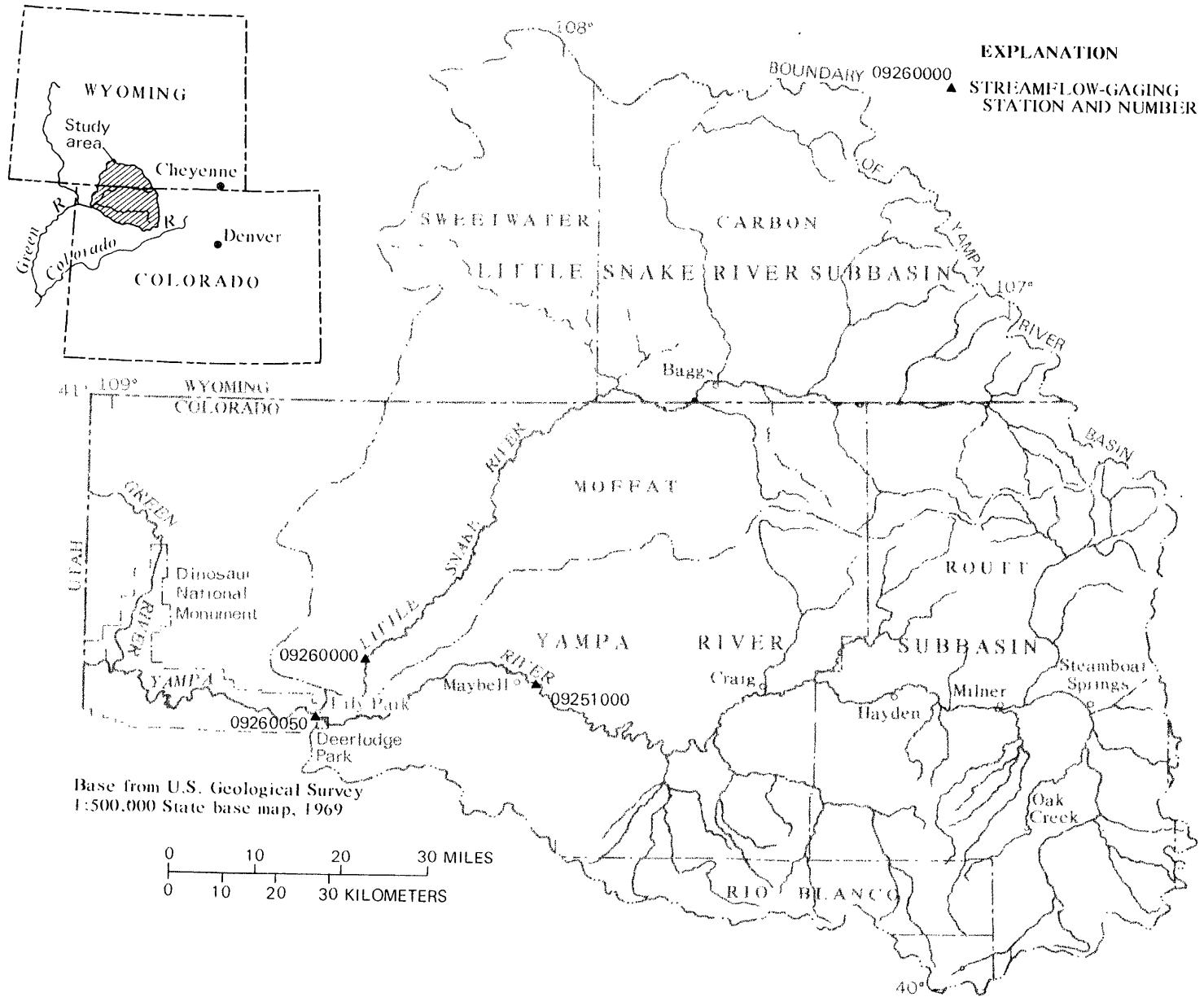


Figure 1.--Yampa River basin east of Dinosaur National Monument showing location of stream gages.



4. To estimate the mean annual sediment load transported through Deerlodge Park and into Yampa Canyon for various assumed reductions in streamflow.
5. To establish a method to predict changes in the sediment budget at Deerlodge Park, if the streamflow frequency distribution, annual streamflow, or annual sediment supply are altered or reduced.

## HYDROLOGY OF THE YAMPA RIVER BASIN

Streamflow data are collected by the U.S. Geological Survey at several locations in the Yampa River basin. Two streamflow-gaging stations upstream from the study reach, 09251000 Yampa River near Maybell and 09260000 Little Snake River near Lily have recorded over 60 years of discharge data from a combined area that represents 89 percent of the entire Yampa River basin (fig. 1). Mean-annual streamflow is 1.1 million acre-ft/yr at the Maybell site, and 0.4 million acre-ft/yr at the Lily site.

Timing and volume of floodflows at both sites are predominantly a function of snowmelt; however, in late summer the streamflow occasionally is influenced by rainstorms. Peak flows for both rivers usually occur between mid-May and mid-June. Extremes for the period of record are 17,900 ft<sup>3</sup>/s on May 19, 1917, for the Yampa River near Maybell, and 14,200 ft<sup>3</sup>/s on May 27, 1926, for the Little Snake River near Lily. Hydrographs depicting mean daily discharges averaged over the period of record for these two sites are presented in figure 2.

Gaging stations 09251000 Yampa River near Maybell and 09260000 Little Snake River near Lily are on main-stem rivers draining subbasins of roughly equal area; 3,410 mi<sup>2</sup> for the basin above the Maybell site, and 3,730 mi<sup>2</sup> for the basin above the Lily site. The two subbasins, however, have striking differences in annual runoff and sediment yield. The Yampa River basin above Maybell contributes 73 percent of the annual streamflow and 27 percent of the annual sediment load of the entire Yampa basin. Conversely, the Little Snake River basin above Lily contributes only 27 percent of the annual streamflow but nearly 69 percent of the annual sediment load (Andrews, 1978).

Suspended-sediment concentrations have been sampled periodically at the Maybell and Lily stations. Daily suspended-sediment discharge (ton/d) is computed by multiplying the daily mean suspended-sediment concentration (mg/L) by the daily mean water discharge (ft<sup>3</sup>/s) and by a coefficient that is based on the unit of measurement of water discharge, and that assumes a specific weight of 2.65 for sediment (Porterfield, 1972). Annual suspended-sediment discharge may be computed from these data by summing daily suspended-sediment discharges when records are sufficient, or by combining the relation between sediment discharge and water discharge with a long-term streamflow-duration curve (Miller, 1951).

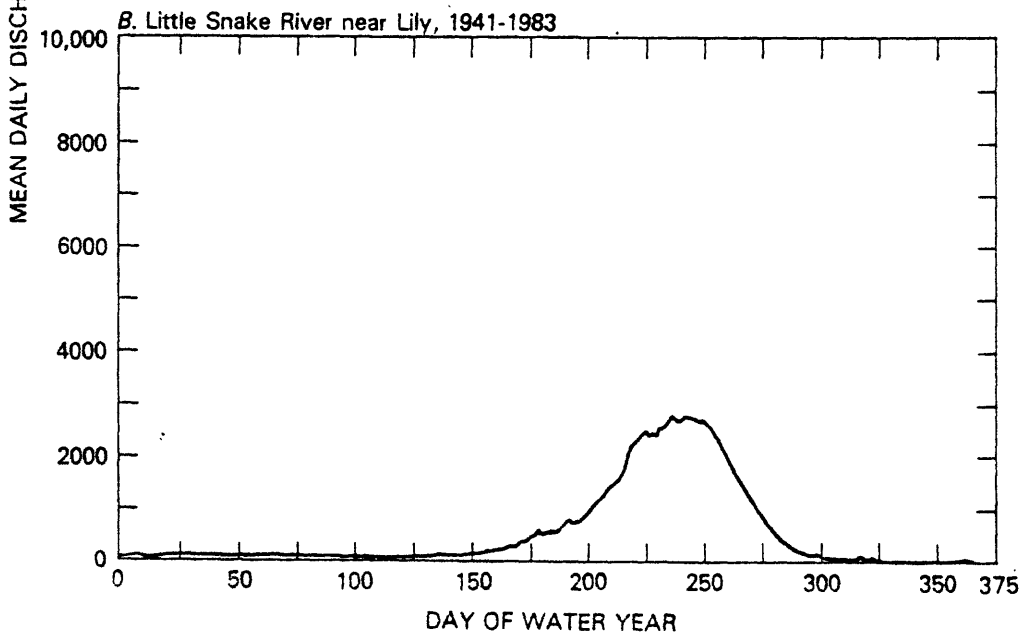
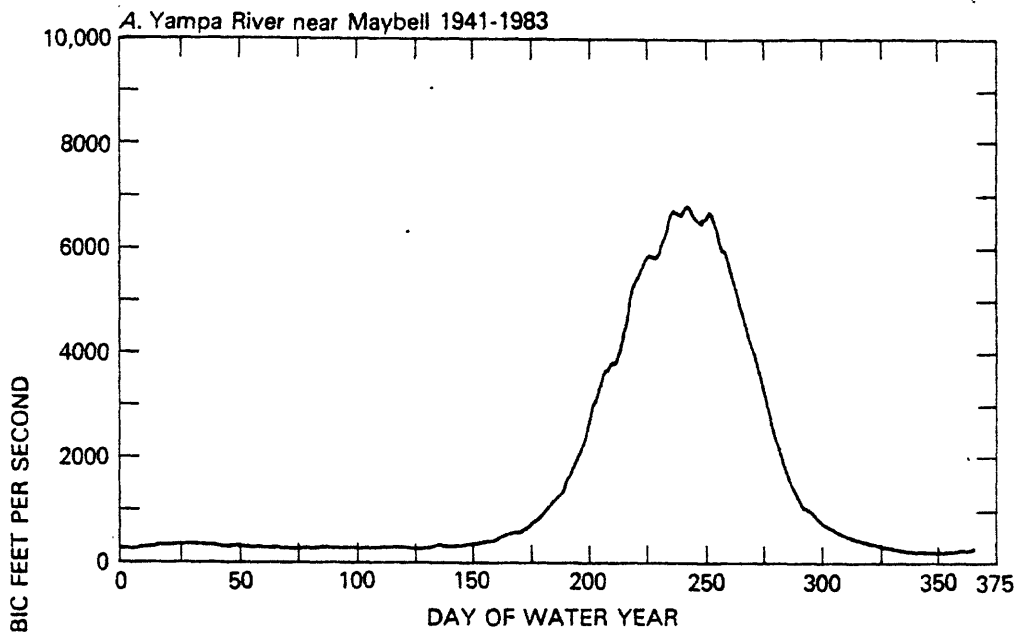


Figure 2.--Hydrographs of mean daily discharges for: A. Station 09251000 Yampa River near Maybell; and B. station 09260000 Little Snake River near Lily.

At the Maybell station, suspended sediment is predominantly in the silt and clay-size range (particle diameter is less than 0.062 mm). At the Lily station, most of the suspended sediment also is in the silt and clay-size range, but about 40 percent is sand size (particle diameter is larger than 0.062 mm, and smaller than 2.00 mm). The size and quantity of sediment transported by the Yampa and Little Snake Rivers are reflected in the appearances of their channels at the gaging stations and downstream before their confluence at Lily Park. The Yampa River, above the confluence, has a well-defined channel with cobble bed and point-bars; the banks are steep and composed of silt and clay-size material. By contrast, the Little Snake River has a bed composed predominantly of sand-size material. Where the river is not confined by bedrock or resistant banks, the channel has numerous braids and transverse channel bars that are exposed at intermediate and low flows. Downstream from the confluence with the Little Snake River, and upstream from the beginning of the Yampa Canyon, the geomorphology of the Yampa River is conspicuously affected by the high sediment contribution from the Little Snake River. Along this reach the Yampa River has a shallow, anastomosing channel and a bed composed of sand-size material.

#### STREAMFLOW OF THE YAMPA RIVER AT DEERLODGE PARK

A streamflow-gaging station was established in 1982 in Deerlodge Park by the U.S. Geological Survey to obtain data for determining annual streamflow and sediment transport into the Yampa Canyon (fig. 3). The gaging station is located approximately one-half mile upstream from the entrance to the Yampa Canyon. River stage at this station, 09260050 Yampa River at Deerlodge Park, was continuously recorded from April 1982 through September 1983. The relation between water-surface elevation and discharge was determined from 35 discharge measurements (Carter and Davidian, 1968). Discharge measurements were made from a boat attached to a fixed cable or by wading. Measured discharge ranged from 646 ft<sup>3</sup>/s to 17,600 ft<sup>3</sup>/s, and shifting of the sand bed occurred between most measurements (fig. 4). Hydraulic geometry relations based on discharge measurements made at this site are presented in table 1. The low value of the exponent (0.059) in the equation of channel width versus discharge resulted because banks at the study section were vertical and resistant to erosion; hence, channel width varied little with discharge. Most adjustment to increasing discharge occurred as change in mean depth and mean flow velocity. Water-surface profiles were surveyed on 12 days when the discharge varied from 930 ft<sup>3</sup>/s to 15,800 ft<sup>3</sup>/s. Although the average slope of the reach varied from 0.00040 ft/ft to 0.00087 ft/ft, no consistent relation between water-surface slope and discharge was apparent. Slope values varied about a mean of 0.00069 ft/ft with a standard deviation of 0.00014.

Daily mean discharges recorded at the Yampa River at Deerlodge Park gage were compared to the sum of daily mean discharges recorded at the Little Snake River near Lily gage and the Yampa River near Maybell gage. The concurrent period of record for these three gaging stations was 548 days, and included peak-flow months for both 1982 and 1983. Daily mean discharges at Deerlodge Park were found to be highly correlated with the sum of daily mean discharges

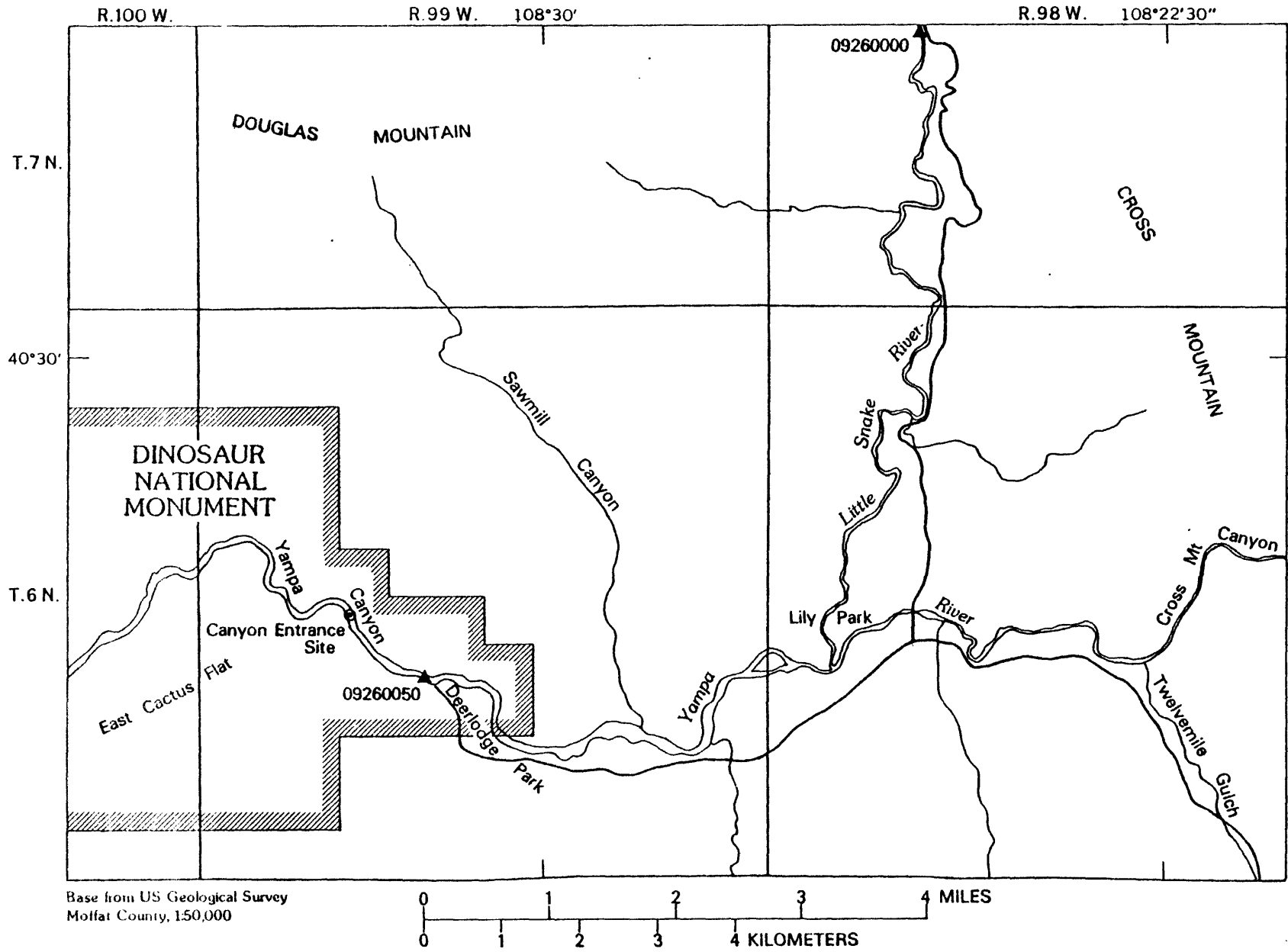


Figure 3.--Principal study sites.

Yampa River at Deerlodge Park, 09260050

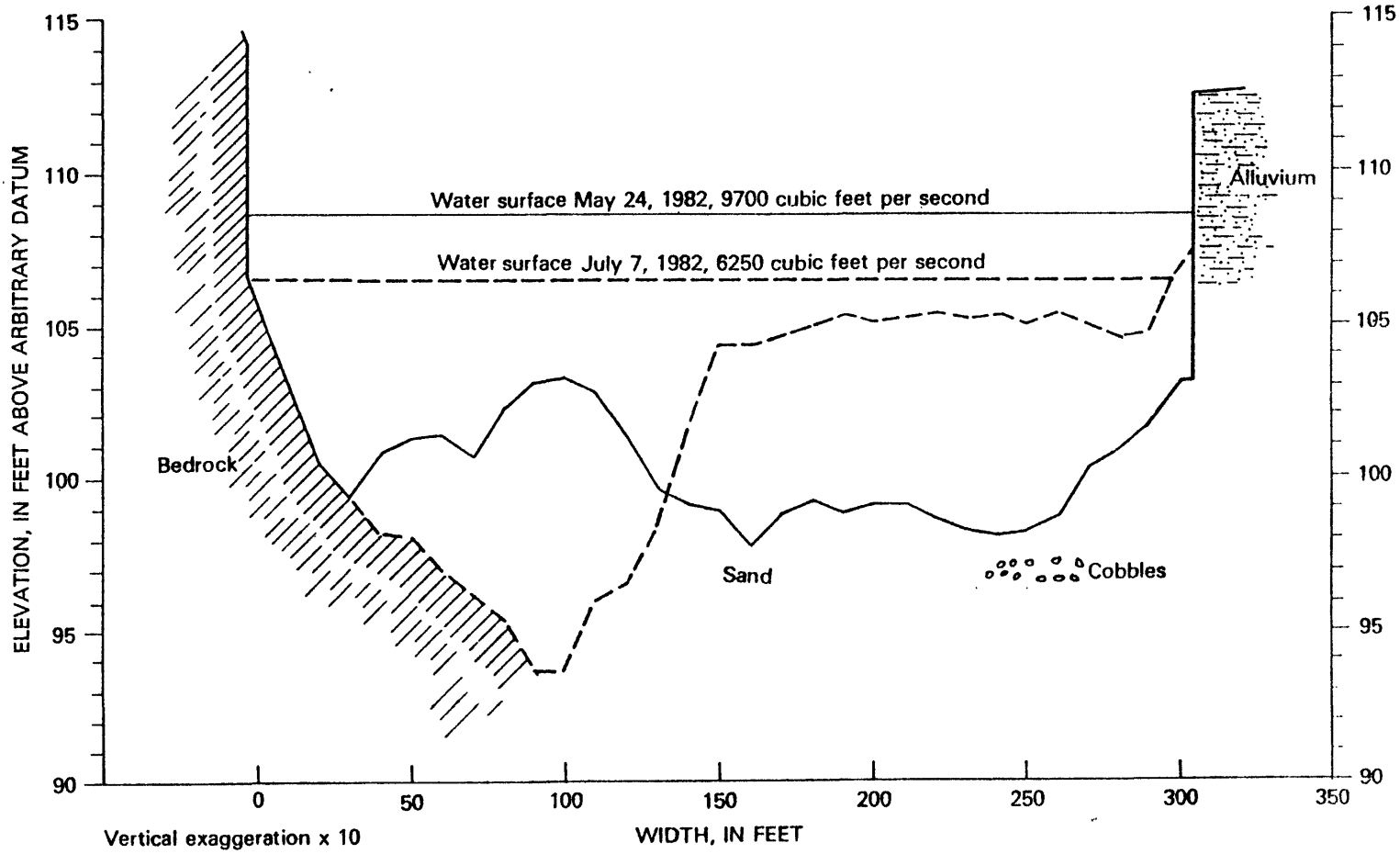


Figure 4.--Channel cross section showing magnitude of scour and fill of bed material.

Table 1.--Hydraulic geometry relations at station 09260050 Yampa River at Deerlodge Park

[W, channel width in feet;  $\bar{D}$ , mean depth in feet;  $\bar{u}$ , mean velocity in feet per second;  $A_f$ , cross-sectional area in square feet; Q, instantaneous discharge in cubic feet per second;  $R^2$ , coefficient of determination; SE, standard error of estimate in percent; n, sample size]

Regression equation	$R^2$	SE	n
$W = 178 Q^{0.059}$	0.18	12	35
$\bar{D} = 0.0227 Q^{0.64}$	.96	13	35
$\bar{u} = 0.251 Q^{0.30}$	.91	9	35
$A_f = 4.04 Q^{0.70}$	.98	10	35

Water surface slope varied about a mean of 0.00069, with standard deviation of 0.00014 and n of 12.

at the Maybell and Lily gages. Linear regression of log-transformed discharge data resulted in the equation:

$$Q_D = 1.74 Q_{\Sigma}^{0.94}, \quad R^2 = 0.98, \quad SE = 18 ,$$

where:

$Q_D$  = daily mean discharge of Yampa River at Deerlodge Park, in  $ft^3/s$ ,

$Q_{\Sigma}$  = sum of daily mean discharges of Yampa River near Maybell and Little Snake River near Lily, in  $ft^3/s$ ,

$R^2$  = coefficient of determination, and

SE = standard error of estimate, in percent.

The regression equation gives about the same answer as simply summing the upstream discharges when the discharge at Deerlodge Park is about 10,000  $ft^3/s$ . However, when the discharge at Deerlodge Park is near 400  $ft^3/s$ , the equation overestimates discharge by about 25 percent. Consequently, historic discharges at the Deerlodge Park gage were estimated by summing historic discharges of the Yampa River near Maybell gage and the Little Snake River near Lily gage. The historic hydrograph of mean daily discharges for the Yampa River at Deerlodge Park is presented in figure 5.

Water years 1982 and 1983 were characterized by high peak discharges, and above-average annual streamflows. The 1982 instantaneous peak discharge at

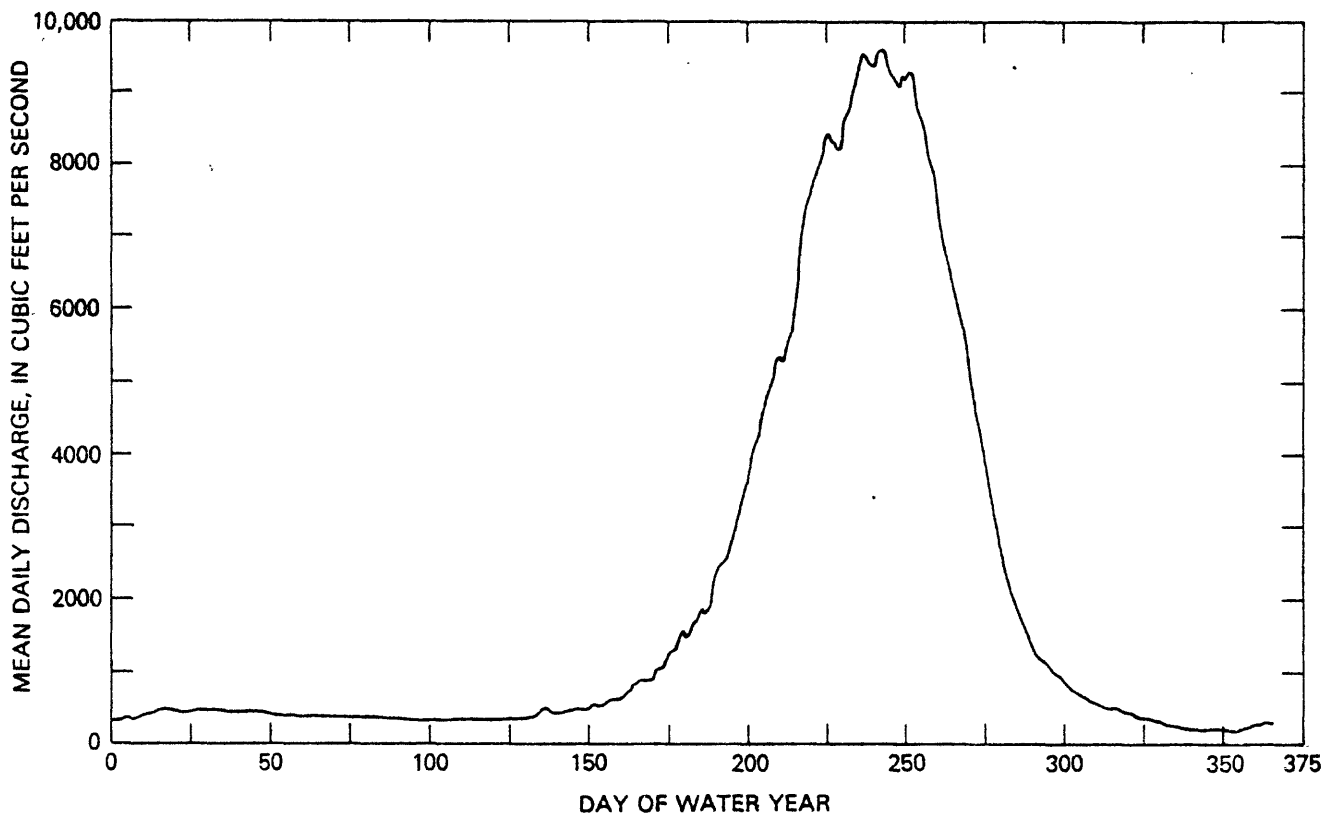


Figure 5.--Hydrograph of mean daily discharges for station 09260050 Yampa River at Deerlodge Park. Extrapolated from daily mean discharges at station 09251000 Yampa River near Maybell and station 09260000 Little Snake River near Lily, 1941-1983.

Deerlodge Park was 16,500 ft<sup>3</sup>/s and the 1983 instantaneous peak discharge was 23,400 ft<sup>3</sup>/s. In 1983, the flood plain at Deerlodge Park was inundated by floodwater for several days during the peak runoff. Recurrence intervals of annual maximum daily mean discharges were estimated for the 1982 and 1983 streamflows at Deerlodge Park using the 43 years of streamflow record, and a Log Pearson Type III analysis (U.S. Water Resources Council, 1981). The 1982 peak daily mean discharge had a recurrence interval of about 3 years, and the 1983 peak daily mean discharge had a recurrence interval of about 20 to 25 years. The combined long-term mean annual streamflow of the Yampa River near Maybell and the Little Snake River near Lily is 1.5 million acre-ft/yr (U.S. Geological Survey, 1982). In 1982, the combined annual streamflow of the Yampa River near Maybell and the Little Snake River near Lily was 1.9 million acre-ft, and in 1983 it was 2.3 million acre-ft.

A flow-duration curve is a cumulative-frequency curve that shows the percentages of time specified discharges are equaled or exceeded during a given period. It combines into one curve the flow characteristics of a stream throughout a range of discharge, without regard to the sequence of occurrence (Searcy, 1959). Historical streamflows at station 09251000 Yampa River near Maybell and station 09260000 Little Snake River near Lily were examined to determine an appropriate period of record for estimating the long-term flow-duration curve at station 09260050 Yampa River at Deerlodge Park. Flow-duration curves calculated from 10-year increments were compared for each site. In the decade of the 1920's, days when discharge was very low occurred much less frequently than in other decades. By contrast, in the decade of the 1930's, days when discharge was very low occurred much more frequently than in other decades. Streamflow of the decades since 1940 has been relatively uniform and has had a greater effect on the present channel morphology than has streamflow from earlier in the century; therefore, only discharge data recorded since 1940 was used in streamflow analysis. A long-term (1941-1983) flow-duration curve for Deerlodge Park was computed from the daily sums of daily mean discharges recorded at the Maybell and Lily gaging stations. This curve is presented in figure 6.

#### SEDIMENT TRANSPORT AT DEERLODGE PARK

The relation between water discharge and sediment discharge at Deerlodge Park was used to quantify the amount of sediment entering the Yampa River Canyon. The total sediment load of a river can be divided into two components: (1) Suspended-sediment, which is the relatively fine material (clay, silt, and some sand-size material) transported in suspension; and (2) bedload which is coarser material (sand, gravel, and cobble sizes) that moves by rolling or bouncing along the bed. Measurements of both suspended sediment discharge and bedload discharge were made at the Deerlodge Park study reach during the spring and summer of 1982 and 1983. Supplemental streamflow and sediment data were collected in 1983 at two additional sites (fig. 3). Suspended-sediment measurements were made at station 09260000 Little Snake River near Lily to provide additional information on sediment entering the Yampa River. Also, discharge measurements were made and sediment samples were



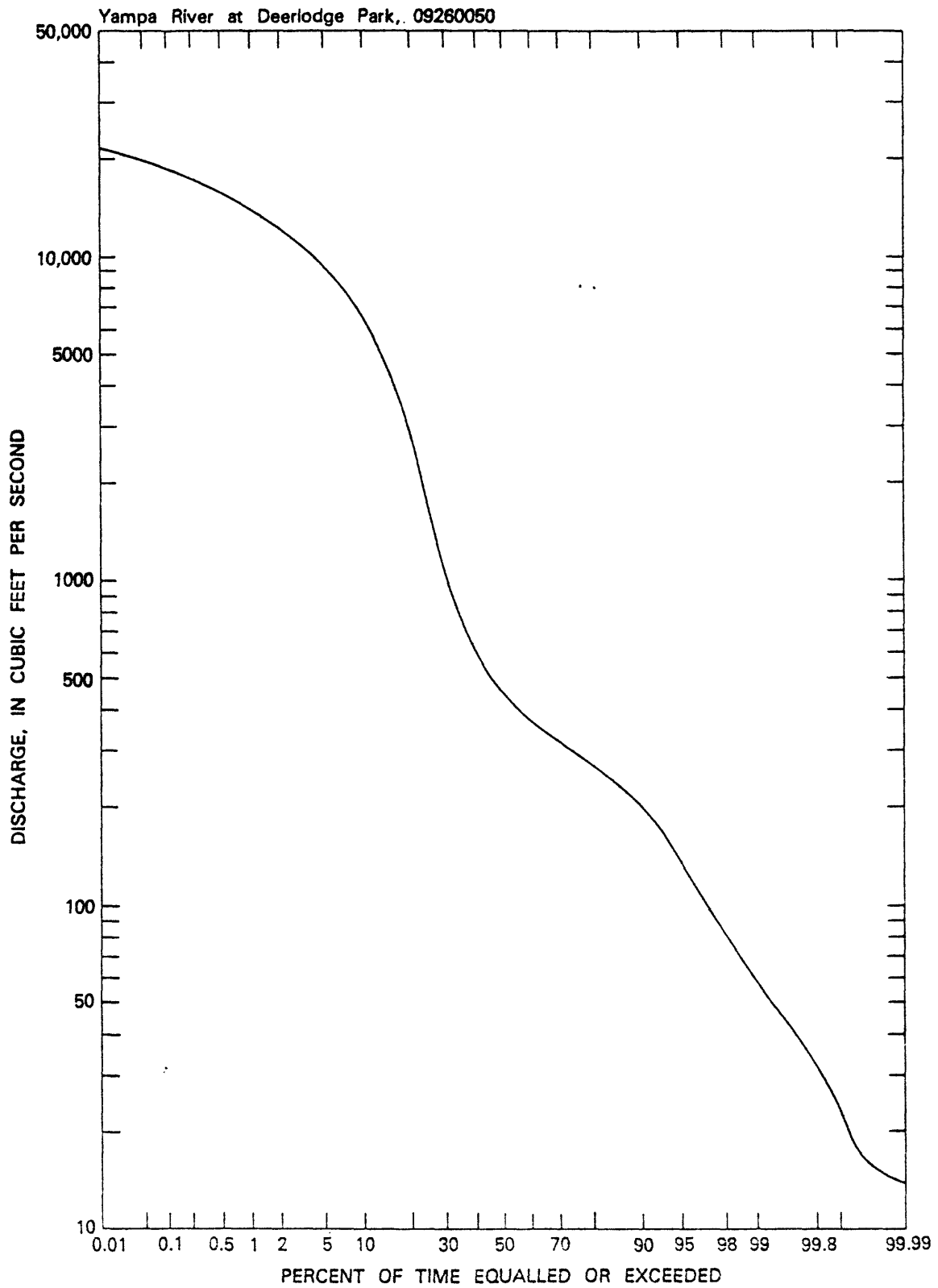


Figure 6.--Estimated flow-duration curve for station 09260050 Yampa River at Deerlodge Park for period 1941-1983.

collected at an ungaged site, Yampa River at Canyon Entrance, to check the accuracy of measurements made at the Deerlodge Park site. The channel at the Canyon Entrance site, which is confined by bedrock and talus, provides a good hydraulic control for water and sediment-discharge measurements.

Suspended sediment was collected at station 09260050 Yampa River at Deerlodge Park at verticals spaced every 15 ft across the channel with a DH-48 or D-74 depth-integrating sampler (Guy and Norman, 1970). Observed suspended-sediment concentrations varied from 137 mg/L to 5,600 mg/L. Bedload was collected at 15-ft intervals across the channel at the Deerlodge Park site using a Helley-Smith bedload sampler (Helley and Smith, 1971; Emmett, 1980). Bed-material samples were collected with a pipe dredge (6-in. diameter) at 50-ft intervals along the cross section. Concentrations and size distributions of suspended sediment collected at station 09260050 Yampa River at Deerlodge Park are shown in table 8. Size distributions of bed material are shown in table 9 and size distributions of bedload are shown in table 10. Discharge, hydraulic-geometry and sediment-size data from station 09260000 Little Snake River near Lily are shown in table 11, and similar data from the ungaged site, Yampa River at Canyon Entrance, are shown in table 12. Tables 8-12 are presented in the Supplemental Data section at the end of the report.

Sediment discharges in the Yampa River at Deerlodge Park were computed from 33 measurements made over a range of discharges. Suspended-sediment discharge in the sampled zone was computed from the mean discharge-weighted sediment concentration, the measured water discharge, and a unit conversion constant (Porterfield, 1972). A correction factor to account for the percentage of streamflow actually sampled with the depth-integrating sampler was applied to the computation of discharge of suspended particles that would also be collected near the bed in the Helley-Smith sampler (particle diameters larger than 0.25 mm), (Colby, and Hembree, 1955). Bedload discharge was computed by dividing the dried sample weight by the total sample time and by the width of the Helley-Smith sampler orifice (0.25 ft), and multiplying by the channel width. Total-sediment discharge was determined as the sum of suspended-sediment discharge and bedload discharge. Size distributions of suspended sediment (table 8) and bedload (table 10) were combined with the appropriate suspended-sediment discharge and bedload discharge to compute sediment discharges by size range. Water discharge, total sediment discharge, suspended-sediment discharge, bedload discharge, and the total sediment discharge in several size categories are presented in table 13 in the Supplemental Data section at the end of the report.

The size distribution of material transported by the Yampa River at Deerlodge Park is summarized in table 2. Most of the riverbed consisted of sand-size material during all discharge measurements in 1982 and 1983. Both the bed material of the channel and the bedload were predominantly medium-to-coarse sands. The average of median grain sizes ( $d_{50}$ ) for bed-material samples was 0.61 mm, and for bedload was 0.57 mm. Bed-material samples that included minor amounts of gravel were highly skewed. Suspended sediment at the Deerlodge Park site varied considerably in size distribution. Silt- and clay-size material (sediment finer than 0.062 mm) comprised 10 to 92 percent of the total suspended-sediment discharge; the mean was 60 percent and the standard deviation was 23.7 percent. The remainder of suspended sediment was

Table 2.--Particle size statistics for sediment in the Deerlodge Park study reach

Type of sediment	Sample size	Median grain size (d <sub>50</sub> in millimeters)		Silt- and clay- size content (percent, by weight, finer than 0.062 millimeter)	
		Mean	Standard deviation	Mean	Standard deviation
Bed material----	34	0.61	0.17	0.1	0.1
Bedload-----	32	.57	.12	.1	.1
Suspended sediment-----	34	----	----	60.0	23.7

in the sand-size range. Virtually all silt- and clay-size material in the Yampa River at Deerlodge Park was transported in suspension. Silt- and clay-size material in bed-material samples averaged less than 1 percent by weight (table 2).

The Yampa River at Deerlodge Park had a mobile bed for the duration of this study; movement of bed material was observed over the entire range of discharges measured in 1982 and 1983. Material comprising the channel bed at Deerlodge Park was in the sand-size range and relatively uniform in size. Bedforms could not be observed due to turbidity and the depth of water. No coarse-grain lag deposits were detected at the section where discharge and sediment measurements were made, and it appeared that all sizes of bed-material particles in the channel could be transported by the prevailing flow regime. The Shield's dimensionless shear stress relation (Shields, 1936) may be used to estimate the particle size of bed material at the threshold of movement for a given shear stress; therefore, the competence (maximum particle size transportable) of the Yampa River at Deerlodge Park may be estimated for various discharges. By definition:

$$d_c = \frac{\bar{D} S}{(\gamma_s/\gamma - 1) \tau_{*c}} \quad (304.8 \text{ mm/ft})$$

where:

- $d_c$  = particle size of bed material in mm at threshold of movement,
- $\bar{D}$  = mean channel depth in ft,
- $S$  = channel slope,
- $\gamma_s/\gamma$  = ratio of specific weights of sediment and water = 2.65, and
- $\tau_{*c}$  = dimensionless critical shear stress.

If  $\tau_{*c}$  is 0.03 (Neill, 1968), then for the average water-surface slope ( $S=0.00069$ ), and the minimum observed mean depth ( $\bar{D}=80$ , see table 7 in the Supplemental Data section at the end of this report),  $d_c=7.69$  mm. Sediment particles of this size on the bed are at the threshold of movement, and all smaller material is mobile under these flow conditions. The median grain size ( $d_{50}$ ) of bed material in the study reach (table 2) is considerably smaller than  $d_c$  (7.69 mm) for this flow depth. The average size of bed material at the 95th percentile ( $d_{95}=3.13$  mm) also is smaller than  $d_c$ , indicating that the majority of material composing the streambed at Deerlodge Park is a size capable of transport at the lowest flows.

No obvious nonlinear trends were detected in the sediment discharge and water discharge data; therefore, sediment transport equations describing the variation in measured sediment discharge as a function of the water discharge were derived by a least-squares linear regression of the log-transformed values. Equations were determined separately for total sediment discharge, suspended-sediment discharge, bedload discharge, and for different size fractions of sediment: coarser than 0.062 mm (sand and gravel), finer than 0.062 mm (silt and clay), 0.062 to 0.25 mm, 0.25 to 1.0 mm, and coarser than 1.0 mm (table 3). Based on values of the coefficient of determination ( $R^2$ ), and standard error of estimate (SE), linear-regression analysis was adequate to account for most of the variance in data of four of the eight sediment categories: total sediment discharge, suspended-sediment discharge, discharge of material coarser than 0.062 mm (sand and gravel), and discharge of material 0.062 to 0.25 mm (fine sand). Variance of the data in other sediment categories was poorly accounted for by linear-regression analysis.

The regression equation for silt and clay-size material (finer than 0.062 mm) in table 3 did not predict well the discharge of this material. The proportion of silt and clay in the suspended-sediment discharge varied considerably (see table 8 in the Supplemental Data section at the end of this report). While the amount of sand transported in suspension varies in phase with discharge, the amount of silt and clay transported is controlled by the supply of these fine materials to the stream. The supply of fine material to a stream reach is influenced by seasonality, the size and duration of runoff generating storms, and the lag effect of the downstream travel of sediment and water waves (Richards, 1982). Regression equations for bedload discharge, for discharge of material in the 0.25 to 1.0 mm range, and for material coarser than 1.0 mm also did not predict well. Transport of coarse sand and gravel is strongly discharge dependent. Variance in these data is large because the sediment discharges of these size ranges were derived from measured bedload discharges, which also had large variances. The variance in measured bedload discharge may be large due to a number of reasons, including temporal variability in bedload discharge which was not accounted for in the sampling procedures (D. W. Hubbell, U.S. Geological Survey, oral commun., 1984).

Seasonal differences in the supply of sediment to a stream or in water temperature may affect sediment discharge. Some rivers, for example, the San

Table 3.--Sediment-transport equations derived from sediment discharges measured at station 09260050 Yampa River at Deerlodge Park

[ $Q_s$ , sediment discharge in tons per day;  $Q$ , water discharge in cubic feet per second;  $R^2$ , coefficient of determination; SE, standard error of estimate in percent;  $n$ , sample size; mm, millimeter]

Type of sediment discharge	Regression equation	$R^2$	SE	$n$
Total-----	$Q_s = 0.290 Q^{1.26}$	0.79	67	31
Suspended-----	$Q_s = 0.125 Q^{1.35}$	0.76	88	33
Bedload-----	$Q_s = 0.702 Q^{0.80}$	0.54	79	31
Sand and gravel-----	$Q_s = 0.0160 Q^{1.48}$	0.82	73	31
Silt and clay-----	$Q_s = 0.486 Q^{1.12}$	0.56	116	31
0.062-0.25 mm-----	$Q_s = 0.000545 Q^{1.77}$	0.88	65	31
0.25-1.0 mm-----	$Q_s = 0.0904 Q^{1.18}$	0.55	130	31
Coarser than 1.0-----	$Q_s = 0.147 Q^{0.76}$	0.24	201	31

Juan River near Bluff, Utah (Leopold and others, 1964, p. 230), exhibit conspicuous differences in the relation of sediment discharge to water discharge during rising spring flows and recessional summer flows. As a result of observations during the 1982 field season, in which suspended-sediment concentrations during rising streamflows appeared to be generally higher than concentrations during recessional streamflows, it was suspected that seasonal differences in sediment discharge may be typical of the Yampa River at Deerlodge Park.

Streamflow and sediment discharge data were reexamined to determine the significance of seasonality on sediment transport through Deerlodge Park. Sediment discharge and water discharge data from 1982 and 1983 were subdivided into groups on the basis of occurrence during the rising hydrograph or the recessional hydrograph. Measurements made from February through May were categorized as rising-hydrograph measurements, and those made from June through July were categorized as recessional-hydrograph measurements. Least-squares linear-regression equations describing measured sediment discharge as a function of water discharge, similar to those in table 3, were recomputed from data in the subgroups. The regression equation slope and intercept values from both subgroups were analyzed with a Student t-test to determine whether significant differences existed between sediment discharge relations associated with rising and recessional hydrographs. At the 95-percent level of significance, no differences between the sediment transport equations representing rising and recessional hydrographs were confirmed for total sediment discharge, suspended-sediment discharge, or the discharge of sediment

in the size ranges of: sand and gravel, silt and clay, 0.062 to 0.25 mm, and 0.25 to 1.0 mm; therefore, one sediment-transport equation for each of these sediment categories was sufficient for subsequent analyses. The relations were significantly different for bedload discharge and for the discharge of sediment coarser than 1.0 mm. However, bedload and the discharge of sediment coarser than 1.0 mm were not highly correlated with streamflow; therefore, determining separate sediment-discharge equations for rising and recessional periods was not reasonable for these two sediment categories.

Occasionally it may be necessary to estimate the total sediment discharge of a river--for example, when reliable bedload discharge measurements are unavailable. Several computational techniques have been developed to estimate sediment discharge for different sizes of bed material. Total sediment discharge at Deerlodge Park was estimated using the Modified Einstein procedure, and these estimated sediment discharges were compared to measured sediment discharges. The Modified Einstein procedure computes total sediment discharge at a cross section for a river primarily having a sand bed. This procedure uses measured hydraulic variables, the mean concentration and particle-size distribution of measured suspended sediment, and the size distribution of material in the bed. The procedure consists of computing the sediment discharge for several ranges of particle sizes by applying different methods of computation for the small particle sizes than for the large particle sizes (Colby and Hembree, 1955). Estimated sediment loads for Deerlodge Park were calculated with the Modified Einstein procedure using a computer program written by Stevens (1978). Calculated total sediment discharges, and sediment discharges in various size categories are presented in table 14 in the Supplemental Data section at the end of this report. Sediment discharges estimated by the Modified Einstein procedure were greater than measured sediment discharges for virtually all observations in every sediment size class. Differences in sediment discharges were largest in the coarse sand-size ranges. Some of the estimated sediment discharges in the 0.5-mm to 1.0-mm, and 1-mm to 2-mm size ranges were much greater than the measured sediment discharges; whereas, in the 4-mm and larger range the estimated sediment discharges were less than the measured sediment discharges.

Disparity between measured sediment discharges and estimated sediment discharges could be a result of undersampling by the Helley-Smith sampler or from overestimation by the Modified Einstein procedure. Measured sediment discharge could be understated because material finer than 0.25 mm (the mesh size of the Helley-Smith sampler) is not totally accounted for in the area of flow sampled by the Helley-Smith sampler. Also, the correction factor applied in suspended sediment computations for the percentage of streamflow actually sampled may be too great if dune bedforms are present (D. W. Hubbell, U.S. Geological Survey, oral commun., 1984). Measured bedload transport rates are subject to error from several sources. Although all bedload samples at Deerlodge Park were collected at the same intervals and on the same cross section, the exact location of the bedload sampler with respect to bedforms was never known. Logistical considerations limited the duration of bedload sampling, and as such, temporal variations in bedload discharge could not be entirely accounted for. Another source of disparity in bedload measurements could be in the hydraulic efficiency of the sampler design (Hubbell, 1964). The ratio of sampler nozzle entrance size to exit size affects the hydraulic

efficiency, which is equivalent to the ratio of mean velocity of water discharge through the sampler to the mean velocity of water discharge which would have occurred through the area occupied by the sampler.

Emmett (1980) recommended that the Helley-Smith sampler not be used for measuring bedload-transport rates for sediment of particle sizes that also are transported as suspended sediment. Although a large amount of sand-size material (0.062 to 2.0 mm) was transported in suspension at Deerlodge Park (see table 8 in the Supplemental Data section at the end of this report), most of this sand was smaller than 0.25 mm and normally passed through the Helley-Smith sample collection bag. A negligible quantity of material less than 0.25 mm in diameter was collected in the Helley-Smith sampler (see table 10 in the Supplemental Data section). Therefore, redundant sampling of material finer than 0.25 mm moving in suspension and as bedload seems to have been avoided at Deerlodge Park.

The Modified Einstein procedure may overestimate some sediment discharges at Deerlodge Park because it is based on the condition of a mobile, continuous, bank-to-bank sand bed. During many measurements made in 1982 and 1983, the Yampa River at Deerlodge Park had a continuous, bank-to-bank sand bed. However, for most measurements made at discharges greater than about 8,000 ft<sup>3</sup>/s, the river bed near the left bank was scoured to bedrock for 15 to 30 percent of the channel perimeter (fig. 4). Field crews observed very low bedload discharges in this section of the river when the channel was scoured to bedrock. The Modified Einstein procedure, which extrapolates transported sediment from the zone of suspended movement to the zone of bedload movement, probably overestimates the total-sediment discharge of the Yampa River at Deerlodge Park for most high discharges because the condition of a mobile, continuous sand bed is unfulfilled at intermediate and high water discharges.

Sediment transport equations derived using sediment discharges estimated with the Modified Einstein procedure (table 4) may be compared with equations in table 3. In general, regression equation exponents are comparable in tables 3 and 4 for most sediment size categories. However, exponents of the equations for discharge of sediment in the 0.25 to 1.0 mm, and coarser than 1.0-mm size ranges are greater in table 4 than in table 3. This implies that Modified Einstein estimates of coarse sand and gravel discharges increase more with water discharge than do comparable sediment discharges based on observed data.

#### ANNUAL SEDIMENT LOADS

The Yampa River channel is adjusted to long-term streamflow and sediment-load regimes. The prevailing hydrologic and sedimentologic conditions must be determined before the potential effects of water resource development in the watershed can be assessed. The average frequency distribution of discharges has been computed from the records of two long-term streamflow-gaging stations. Annual sediment loads were computed by the streamflow-duration, sediment-transport-equation method described by Miller (1951). This method is applicable when the gaging-station record of streamflows is sufficient to

Table 4.--Sediment-transport equations derived from sediment discharges estimated with the Modified Einstein procedure at station 09260050 Yampa River at Deerlodge Park

[ $Q_s$ , sediment discharge in tons per day;  $Q$ , water discharge in cubic feet per second;  $R^2$ , coefficient of determination; SE, standard error of estimate in percent;  $n$ , sample size; mm, millimeter]

Type of sediment discharge	Regression equation	$R^2$	SE	$n$
Total-----	$Q_s = 0.143 Q^{1.36}$	0.80	76	33
Sand and gravel-----	$Q_s = 0.00946 Q^{1.57}$	0.82	82	33
Silt and clay-----	$Q_s = 0.231 Q^{1.21}$	0.58	133	33
0.062-0.25 mm-----	$Q_s = 0.00125 Q^{1.69}$	0.86	74	33
0.25-1.0 mm-----	$Q_s = 0.0108 Q^{1.48}$	0.74	103	33
Coarser than 1.0 mm---	$Q_s = 0.00130 Q^{1.45}$	0.52	241	33

define the frequency of discharge occurrence (flow duration), and when data are available to construct a relation between sediment discharge and water discharge. The annual sediment load transported by increments of discharge is computed by combining the relation between sediment discharge and water discharge (sediment transport equation) with the average frequency of discharge occurrence (flow-duration curve). This technique commonly utilizes total sediment discharge, or suspended sediment discharge versus water-discharge equations; however, it also may be used with sediment transport equations of other material sizes or categories, such as the sediment transport equations in tables 3 and 4.

The frequency distribution of Yampa River discharges during the last 43 years of record is shown in figure 6. This flow-duration curve was combined with sediment-transport equations derived from measured data in table 3 to compute: (1) Annual total sediment load; (2) annual suspended sediment load; (3) annual discharge of bedload; and (4) annual sediment loads of material in the sand-gravel- and silt-clay-size categories. The annual total sediment load computed using the sediment transport equation derived from measured sediment discharges was 2.04 million ton/yr (table 5). The annual suspended sediment load was 1.94 million ton/yr, and the annual discharge of bedload was 0.10 million ton/yr. Therefore, bedload constitutes about 5 percent of the total sediment load transported through Deerlodge Park annually. This proportion for bedload seems reasonable; based on observations from instantaneous sediment discharge measurements, bedload discharge as a percentage of total sediment discharge varied from 1 to 32 percent and averaged 7 percent (see



table 13 in the Supplemental Data section at the end of this report). The sum of the annual sand-gravel- and silt-clay-size loads, which should equal the annual total sediment load, was 1.80 million tons--12 percent less than the computed annual total sediment load. This discrepancy probably exists because of the relatively poor definition of sand-gravel- and silt-clay-size material discharges by the linear-regression equations in table 3. Sediment loads were not computed for any other particle-size categories presented in table 3 because of low R<sup>2</sup> values and high standard errors of estimates associated with those transport equations.

Table 5.--Annual sediment loads, station 09260050 Yampa River at Deerlodge Park

Type of sediment load	Measured (tons per year)	Estimated with Modified-Einstein (tons per year)
Total-----	2,040,000	2,420,000
Suspended-----	1,940,000	1,880,000
Bedload-----	100,000	-----
Sand and gravel-----	790,000	1,040,000
Silt and clay-----	1,010,000	1,050,000

Annual sediment loads for the Yampa River at Deerlodge Park also were computed with sediment transport equations derived from sediment discharges estimated by the Modified Einstein procedure (table 4). Annual sediment loads computed from estimated sediment discharge data were compared to annual sediment loads computed from measured sediment discharge data (table 5). Annual total sediment load computed with the sediment transport equation derived from estimated sediment discharges was 2.42 million ton/yr, a value 16 percent greater than that computed with the sediment transport equation derived from measured sediment discharges. The Modified Einstein procedure does not provide a bedload estimate; therefore, no annual bedload discharge was computed.

Closer inspection of the annual sediment loads in table 5 reveals that the annual silt-clay-size load computed with the sediment transport equation derived from estimated sediment discharges was only 4 percent greater than the annual silt-clay-size load computed with the equation based on measured sediment discharges. By contrast, the annual sand-gravel load computed with the equation based on estimated sediment discharges was 32 percent greater than the annual sand-gravel load computed with the equation based on measured sediment discharges. The discrepancy in computed sand-gravel loads is probably due to undersampling of bedload by the Helley-Smith sampler, overestimation of sand and gravel discharges by the Modified Einstein procedure, or cumulative error that resulted from using sediment transport equations that

did not adequately account for the variance in sediment discharge and water discharge data. Since sediment transport equations based on measured sediment discharges have been derived for more types of sediment discharge than have equations based on estimates from the Modified Einstein procedure, subsequent analysis of sediment transport in the Deerlodge Park reach will utilize the measured sediment discharge versus water discharge relations and their corresponding annual sediment loads.

The annual total sediment load of 2.04 million ton/yr based on 1982 and 1983 measurements agrees with Andrews' (1978, p. 11) estimate of annual total sediment load for Deerlodge Park of 2.0 million ton/yr. His estimate was based on suspended-sediment loads measured at station 09251000 Yampa River near Maybell and station 09260000 Little Snake River near Lily, bedload estimates computed with the Meyer-Peter and Mueller (1948) formula, and an adjustment for the intervening ungaged drainage area.

The flow-duration, sediment-transport-equation method of computing annual sediment loads (Miller, 1951) estimates the amount of annual sediment load transported by successive increments of water discharge, of a given duration. These incremental sediment loads are summed to give the long-term annual sediment load. Cumulative increments of total sediment load are plotted against discharge in figure 7, and the relative portion of total annual sediment load transported by streamflow greater than a specified level is thus illustrated. Approximately one-quarter of the annual total sediment load transported by the Yampa River through Deerlodge Park is carried by discharges greater than 12,000 ft<sup>3</sup>/s. On average, such flows are equaled or exceeded about 2.5 percent of the time (fig. 6), or about 9 days per year.

#### ESTIMATED IMPACTS OF WATER RESOURCE DEVELOPMENT

Sediment loads computed for the Yampa River at Deerlodge Park are estimates of long-term, average sediment transport through this reach and into the Yampa Canyon. The annual sediment load and streamflow are influenced by geomorphic, hydrologic, and climatologic conditions prevailing today and in the recent past. The Yampa River appears to be in equilibrium through the Deerlodge Park reach. Transport of material through this reach is equal to the amount of material supplied to it, on an average basis. No physical evidence exists to suggest long-term aggradation or degradation in Deerlodge Park. The flood plain is broad and has no strath terraces to suggest recent progressive downcutting by the river. The river is not bordered by berms or other overbank deposits that would indicate progressive aggradation. Large cottonwood trees growing on the flood plain indicate that the level of the flood plain has been relatively constant for several decades. Also on the flood plain, near the U.S. Geological Survey gaging station, are adobe and sod buildings that date from about 1903 (Glade Ross, National Park Service, oral commun., 1983). Comparison of the pattern and position of the Yampa River from Lily Park to the canyon entrance, documented by survey in 1922 and by aerial photography in 1970, reveals no changes except those typical of rivers transporting large sand loads, such as bend migration and bar formation.

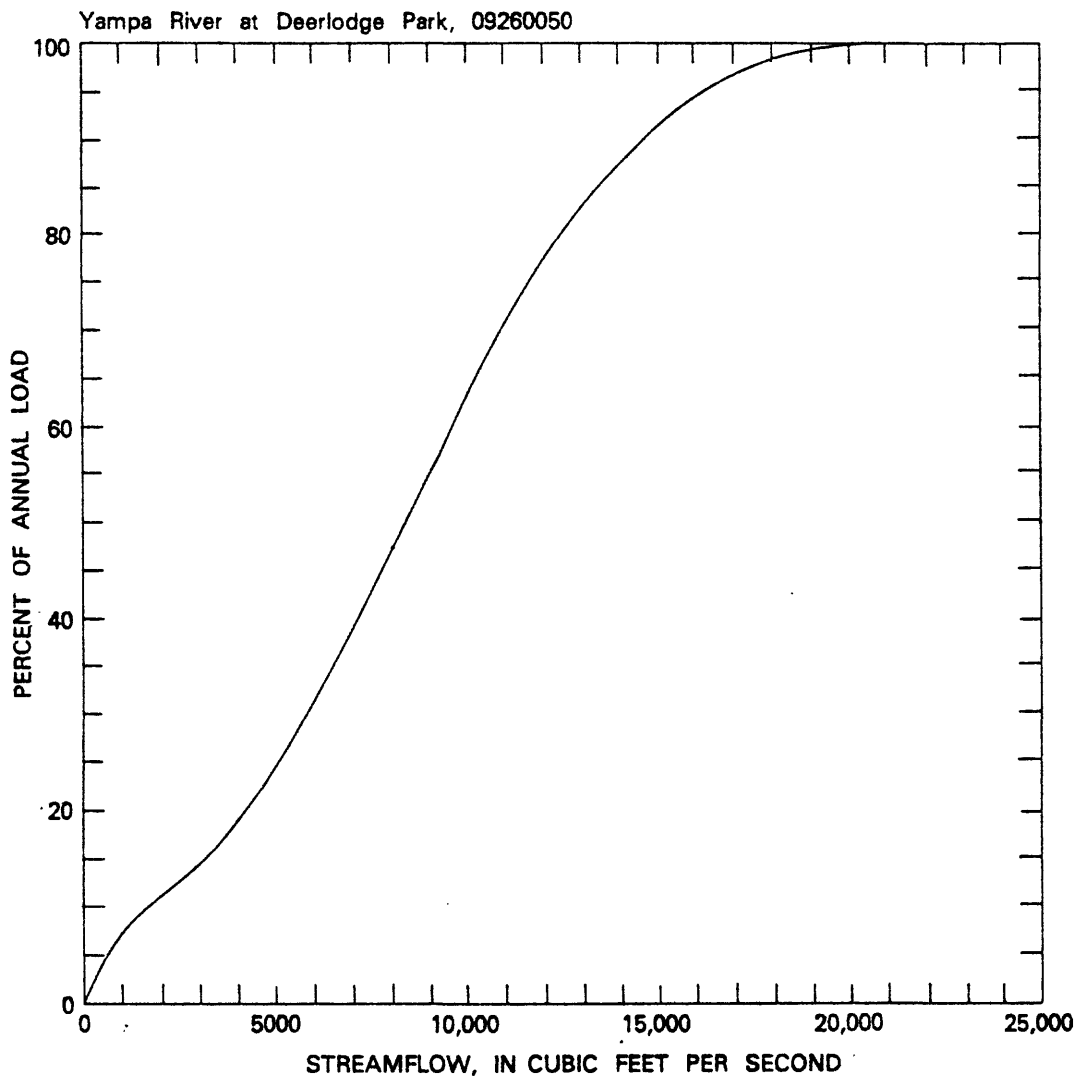


Figure 7.--Cumulative sediment load versus discharge relation, showing the percentage of annual total sediment load transported by flows less than or equal to a given discharge station 09260050 Yampa River at Deerlodge Park.

The pattern of the Yampa River through Dinosaur National Monument is controlled by the local geology, but the character of the river, its local bed and bank conditions, and the distribution of riparian vegetation are determined by the prevailing streamflow and sediment transport regime. Biological and physical characteristics of this river system are affected by seasonally controlled streamflows and intermittent transport and storage of sediment. Much of the sand- and silt-size material introduced into the canyon reach from Deerlodge Park is mobile at the lowest discharges; however, high discharges, though relatively infrequent and of short duration, transport a large part of the total annual sediment load (fig. 7).

Reduced flood peaks and sediment transport through a river reach can result in changes in channel geometry, bed-material size, and bank stability. Schumm (1977, p. 159) summarized the metamorphoses of several rivers in response to changes in mean annual flood, mean annual discharge, and type of sediment load. Regulation of flood peaks can have pronounced effects on the distribution of riparian vegetation as observed on the Green River above the Yampa River (Potter and others, 1983). Dense vegetation encroaching on a channel can promote accumulation of sediment and result in channel-width reduction. A reduction in annual streamflow can have a similar effect on channel geometry, sediment transport, and riparian conditions.

The quantity and composition of sediment carried by a river also are significant factors affecting river morphology. When the transport of sediment through a river reach is equal to the amount of sediment supplied to it, the river is said to be in equilibrium, or graded. Changes in the amount of sediment supplied to a reach can disrupt equilibrium and lead to aggradation or degradation of the channel. Sediment surplus (or deficit) equals the difference between supply to the reach and transport through the reach. Sediment supply may be reduced progressively because of changes in climate or land management that result in lower sediment yield, or because sediment is being stored upstream in the channel or flood plain. More abrupt reductions in sediment supply occur when sediment is trapped in manmade impoundments. Depletion of annual streamflow due to transbasin diversions may be accompanied by a reduction in transport capacity below a diversion structure, resulting in diminished sediment supplied to downstream reaches.

The annual total sediment load can be reduced significantly if the magnitude and duration of the highest increments of streamflow are altered, even though the volume of annual streamflow remains unchanged. Since construction of Flaming Gorge Reservoir on the Green River in Wyoming, the magnitude and duration of high flows have been reduced, while the duration of low flows has increased. Annual streamflow below the dam is equal to pre-dam annual streamflow; but, the annual sediment load measured at a gaging station located 106 mi downstream has declined by 54 percent (E. D. Andrews, U.S. Geological Survey, oral commun., 1983).

The potential effects of altering the distribution of discharges on sediment transport through Deerlodge Park have been examined for several assumed flow durations of the Yampa River. The historic duration of streamflows (curve A, fig. 8) was decreased or increased by percentages equivalent to the changes observed in the Green River near Jensen, Utah (station 09261000), flow duration following the construction of Flaming Gorge Reservoir. The assumed

flow-duration curve (curve B, fig. 8) was drawn with the altered discharge distribution. Annual streamflows represented by curves A and B were both 1.47 million acre-ft/yr. The annual total sediment load for scenario B was computed with the flow-duration, sediment-transport-equation method previously described, and was found to be 1.89 million ton/yr, a 7-percent reduction from the sediment load transported by the prevailing flow regime.

#### SEDIMENT BUDGET AT DEERLODGE PARK

Potential changes in channel morphology will depend principally on the temporal distribution of streamflow, and the degree to which the balance of sediment transport and supply is disrupted. A sediment budget analysis has been used to predict gross changes in sediment storage of the Yampa River at Deerlodge Park if the prevailing streamflow or sediment supply are altered. A sediment budget is the relation between sediment outflow (transport), sediment inflow (supply), and sediment storage in a particular river reach. Sediment budget analysis can be used as a planning tool to: (1) Estimate sediment surplus or deficit under the assumed streamflow frequency distribution, mean annual streamflow and sediment supply; and (2) identify levels of reduced streamflow and sediment supply that may result in negligible sediment surplus or deficit in the Deerlodge Park reach. By identifying annual sediment loads through Deerlodge Park, the analysis will quantify the amount of sediment estimated to enter the Yampa Canyon under assumed reduced streamflows. These data will be useful in ongoing studies of substrate and sediment transport in downstream canyon reaches.

Elements of the sediment budget at Deerlodge Park, stated in terms of annual sediment surplus or deficit, are presented in table 6. The scenarios in table 6 are based on hypothetical conditions resulting from altered streamflow and(or) reduced sediment supply. Actual changes in the sediment budget will depend on several factors. Amounts of sediment supply are assumed in this illustration, but the actual volume of sediment supplied to Deerlodge Park will be influenced by the location of impoundments in the basin. The annual total sediment load (transport) is computed using an assumed average annual streamflow, the corresponding flow-duration curve, and the prevailing total sediment discharge versus water discharge relation. If streamflow and(or) sediment supply are drastically reduced, however, indeterminate changes in the relation between sediment discharge and water discharge may occur over a period of years, thereby affecting estimates of sediment transport.

Any reduction of annual streamflow probably will involve a reduction of the magnitude and duration of the highest discharges and possibly an increase in the duration of the lower discharges. To estimate the effect of reduced annual streamflow on sediment transport and the sediment budget at Deerlodge Park, the upper part of the 43-year flow-duration curve (fig. 6) was arbitrarily reduced by six intervals. The resulting flow-duration curves are presented in figure 9, and they were used to compute annual sediment loads for the scenarios in table 6. These curves were arbitrarily derived and are presented only for the purpose of illustration. Annual streamflows were computed from the flow-duration curves by summing increments of discharge as described by Miller (1951). Reductions from the prevailing annual streamflow ranged from 9

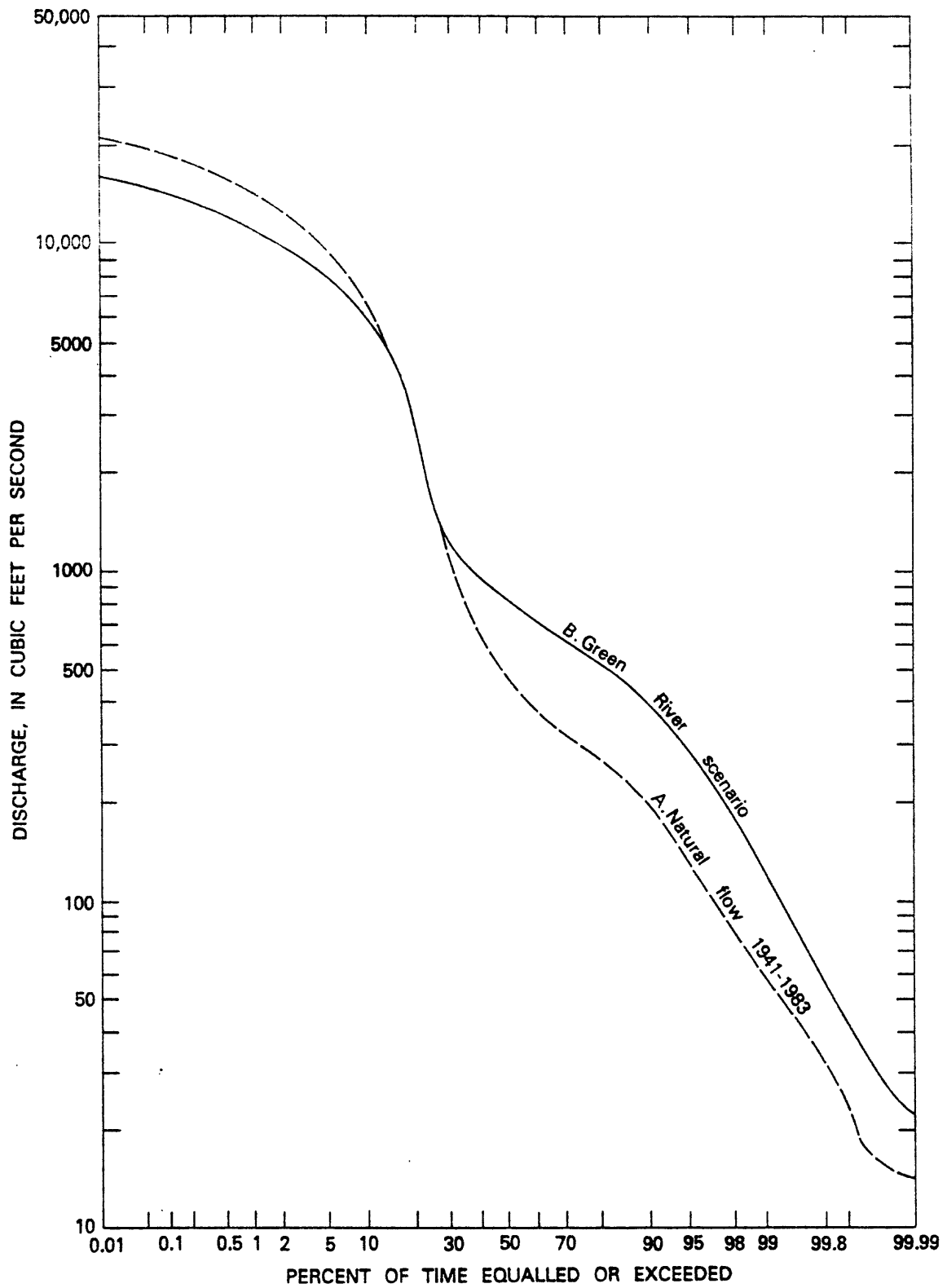


Figure 8.--Flow-duration curves of natural streamflow at Deerlodge Park, and assumed altered streamflow. Curve B is based on observed changes in Green River flow-duration following construction of Flaming Gorge Reservoir.

Table 6.--Sediment budget showing anticipated sediment surplus, or deficit, at station 09260050 Yampa River at Deerlodge Park resulting from various combinations of reduced or altered annual streamflow and reduced annual sediment supply

[M TON/YR, million tons per year; M AF/YR, million acre-feet per year]

	ANNUAL SEDIMENT SUPPLY SCENARIOS						
	1 PREVAILING SEDIMENT SUPPLY 2.0 M TON/YR	2 5 PERCENT REDUCTION 1.9 M TON/YR	3 10 PERCENT REDUCTION 1.8 M TON/YR	4 20 PERCENT REDUCTION 1.6 M TON/YR	5 30 PERCENT REDUCTION 1.4 M TON/YR	6 50 PERCENT REDUCTION 1.0 M TON/YR	7 70 PERCENT REDUCTION 0.6 M TON/YR
ANNUAL STREAMFLOW/ SEDIMENT TRANSPORT SCENARIOS	SURPLUS (+) DEFICIT (-)	SURPLUS (+) DEFICIT (-)	SURPLUS (+) DEFICIT (-)	SURPLUS (+) DEFICIT (-)	SURPLUS (+) DEFICIT (-)	SURPLUS (+) DEFICIT (-)	SURPLUS (+) DEFICIT (-)
A PREVAILING STREAMFLOW= 1.47 M AF/YR TOTAL LOAD=2.0 M T/YR	0.0	-0.1	-0.2	-0.4	-0.6	-1.0	-1.4
B GREEN RIVER SIMULATION= 1.47 M AF/YR TOTAL LOAD=1.9 M T/YR	0.1	0.0	-0.1	-0.3	-0.5	-0.9	-1.3
C 9% REDUCTION= 1.34 M AF/YR TOTAL LOAD=1.8 M T/YR	0.2	0.1	0.0	-0.2	-0.4	-0.8	-1.2
D 23% REDUCTION= 1.13 M AF/YR TOTAL LOAD=1.4 M T/YR	0.6	0.5	0.4	0.2	0.0	-0.4	-0.8
E 37% REDUCTION= 0.92 M AF/YR TOTAL LOAD=1.0 M T/YR	1.0	0.9	0.8	0.6	0.4	0.0	-0.4
F 50% REDUCTION= 0.73 M AF/YR TOTAL LOAD=0.8 M T/YR	1.2	1.1	1.0	0.8	0.6	0.2	-0.2
G 59% REDUCTION= 0.60 M AF/YR TOTAL LOAD=0.6 M T/YR	1.4	1.3	1.2	1.0	0.8	0.4	0.0
H 65% REDUCTION= 0.51 M AF/YR TOTAL LOAD=0.4 M T/YR	1.6	1.5	1.4	1.2	1.0	0.6	0.2

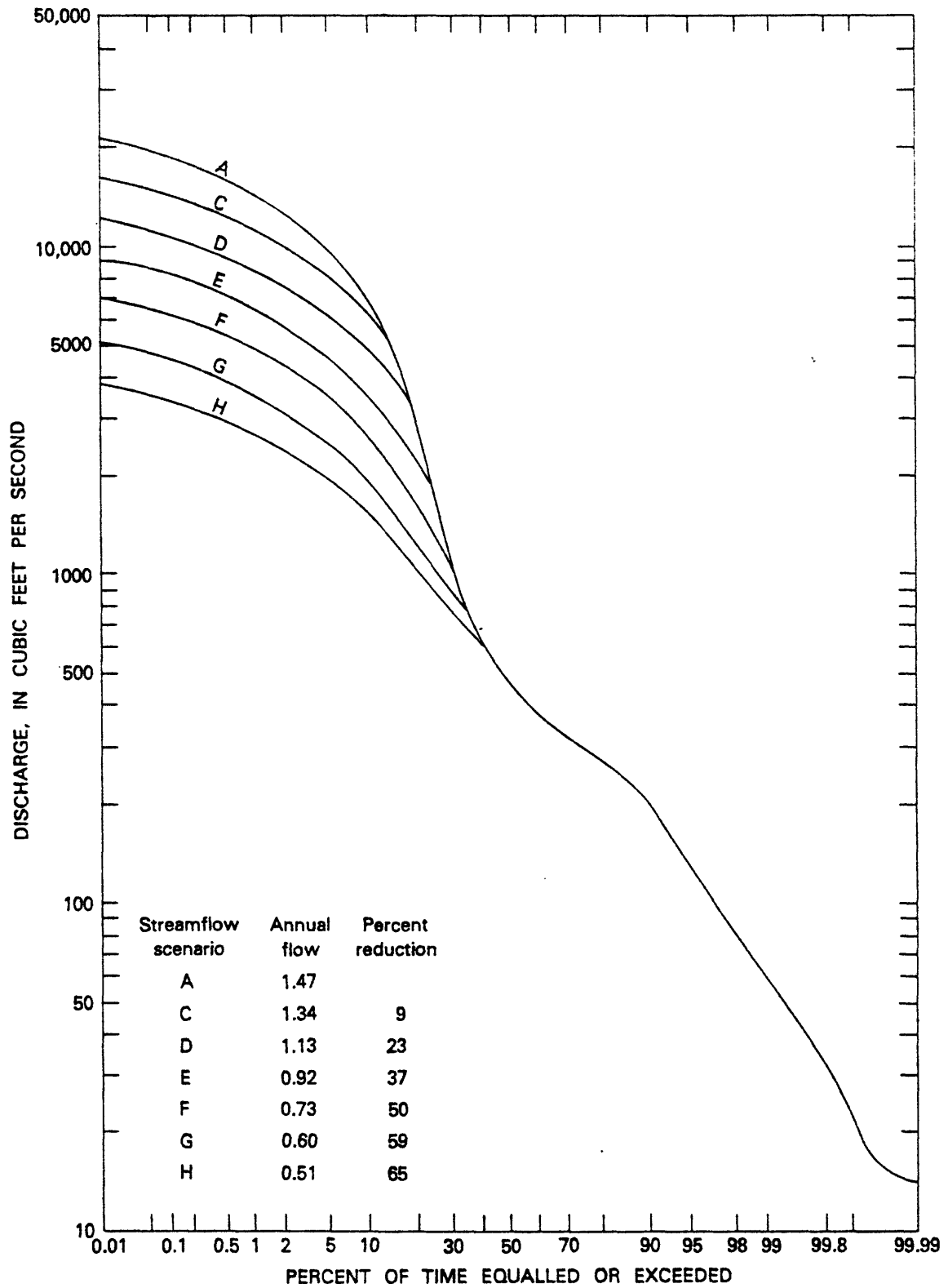


Figure 9.--Flow-duration curves and annual streamflow totals used in the sediment budget.



to 65 percent. A flow-duration curve expresses the probability that a given daily discharge will be equaled or exceeded over a period of years. Shape of the flow-duration curve is dependent on the frequency distribution of daily discharges. Rivers with equal volumes of annual streamflow, but different distributions of daily discharges, will have different flow-duration curves. Each flow-duration curve in figure 9 represents only one of numerous possible discharge distributions for a given annual streamflow.

Annual total sediment loads transported in scenarios of reduced streamflow (fig. 9) were computed by the flow-duration, sediment-transport-equation method described previously. These annual sediment loads are presented in the rows of table 6. The columns represent assumed annual sediment supplies. Streamflow scenario A and sediment supply scenario 1 summarize prevailing conditions in the Deerlodge Park reach. Annual streamflow of 1.47 million acre-ft/yr, with a streamflow frequency distribution represented by the flow-duration curve in figure 6, transports a total sediment load of 2.0 million ton/yr, of which 0.8 million ton/yr is sand-size or larger (table 5). Equilibrium conditions in the Yampa River at Deerlodge Park indicate no surplus or deficit of sediment over a period of years. Therefore, the prevailing supply to Deerlodge has been estimated to be 2.0 million ton/yr.

Combinations of annual streamflow and annual sediment supply in scenarios A1, B2, C3, D5, E6, and G7 of table 6 result in little or no sediment surplus or deficit. The river, in these scenarios, attains an equilibrium in sediment supply and transport on an average annual basis, but in all scenarios except A1, the occurrence of high streamflows is reduced (fig. 9). The scenarios presented in this analysis assume a constant relation between sediment discharge and water discharge; however, if large changes occur in the flow regime, the sediment discharge-water discharge relation also could change. Reductions in peak streamflow will be accompanied by changes in channel form at Deerlodge Park (Mackin, 1948; and Leopold and Maddock, 1953) and riparian vegetation throughout Dinosaur National Monument (Potter and others, 1983), even though the sediment budget may remain in equilibrium.

Other possible combinations of annual streamflow and annual sediment supply are shown in table 6. Annual total sediment loads were computed using the flow-duration curves in figure 9. In several instances, the annual surplus or deficit of sediment in Deerlodge Park is significantly greater than zero. Under these scenarios, problems with channel aggradation or degradation are more severe and occur over a short period of time. Annual sediment transport exceeds annual sediment supply in the scenarios in the upper right part of table 6. Varying degrees of sediment budget deficits result from these scenarios. Sediment budget surpluses result from supply-transport scenarios shown in the lower left part of table 6. As an example, scenario B-1 represents a situation that could exist if the prevailing annual sediment supply and annual streamflow were unchanged, but the duration of Yampa River flows was altered to the degree that has occurred at the Jensen gage located 106 mi downstream from Flaming Gorge Reservoir on the Green River (fig. 8). Annual sediment supply remains 2.0 million ton/yr, but annual sediment transport has been reduced to 1.9 million ton/yr, resulting in a 0.1 million ton/yr surplus of sediment at Deerlodge Park.

Response of the Yampa River channel to streamflow and sediment supply scenarios that lead to a sediment budget surplus or deficit may be described in general terms at best. When the amount of sediment transported is greater than the sediment supply, channel degradation will occur and will continue until stream gradient is decreased or the bed is armored with material too large to be transported. In Deerlodge Park the Yampa River has an alluvial channel, but bed probing at low flow and observations of scour at high flow indicated the presence of coarse-grained material and local bedrock several feet below the sandy bed material. A deficiency of alluvial sediment in the Deerlodge Park reach probably would result in channel degradation over a period of years to this coarse material or bedrock. The amount of degradation, the degree to which slope could increase and the time involved are difficult to predict for the entire reach, but scour at the Deerlodge Park gage site probably would be, at most, on the order of 10 ft below the present low-flow bed profile (fig. 4).

Reduced streamflow and(or) scour accompanying a sediment budget deficit in Deerlodge Park would change the stage-discharge relationship there. Flood flows of a given discharge would inundate banks to a lower level and encourage the establishment of riparian vegetation on banks and bars that are now intermittently flooded and scoured. Flourishing vegetation would result in sediment deposition on banks and bars and cause the river channel to narrow and deepen.

Streamflow and supply scenarios that result in a sediment budget surplus would have different effects on the channel in Deerlodge Park. Sediment would be deposited in the channel, raising the bed elevation and increasing the frequency with which floods inundate the flood plain. Some sediments carried at higher flows may be added to the flood plain by overbank deposition. Often the slope of an aggrading river reach increases; this is possible in Deerlodge Park. Schumm (1977, p. 133) notes several different channel adjustments that can occur if streamflow is reduced and sediment load is increased or remains constant, including an increase or decrease in channel width, an increase in the width to depth ratio, reduced sinuosity, and increased slope. A channel eventually will achieve a new equilibrium, but complete adjustment will require a long period of time. Channel instability can be anticipated until equilibrium is attained.

The river channel in the Yampa Canyon also will be affected by long-term changes in streamflow regime or sediment supply. If the timing or magnitude of peak discharges are significantly altered, sand deposited on banks and bars from late summer through winter may not be swept away seasonally. These formerly transient features, largely composed of sand, could become more permanent during periods of flow regulation through armoring or the growth of vegetation. A channel restricted by resistant banks will have a reduced capacity to transmit short-duration, high-volume streamflows, thereby increasing the potential for flooding of lowland areas (Taylor, 1978). Kellerhals and Gill (1973) reported that regulation of main-stem rivers in northern Canada upset the phase of discharge regime with respect to tributary flow. Floods on tributaries of regulated Canadian streams were more likely to occur when the river stage at the confluence was considerably lower than normal. In the Yampa Canyon, a similar situation could permit bars to build near tributary confluences over a period of years. These features, like residual

banks and point bars, would become colonized by vegetation above the flood level of the new flow regime.

Reductions in annual sediment supply to the Yampa Canyon also will affect the river channel to some degree. In the Yampa Canyon, extensive net degradation of long reaches of the channel that often accompanies a sediment budget deficit probably will not occur because the channel flows on bedrock, talus, and coarse debris from tributaries. If the sediment load is drastically reduced, local erosion of sand from some beaches, bars, and pools may occur, as it has in places on the Colorado River below Glen Canyon Dam (Howard and Dolan, 1981).

The nature of changes in the river channel of the Yampa Canyon that would accompany a long-term surplus in the sediment budget are more difficult to ascertain. The sediment supply to Yampa Canyon is equal to sediment transport through Deerlodge Park. Average channel slope through the Yampa Canyon is much greater than channel slope through Deerlodge Park; therefore, all sediment supplied from Deerlodge Park should be transported through the Yampa Canyon on a long-term basis. However, on a year-to-year basis, problems due to aggradation could occur locally in the Canyon where there are low river gradients over short reaches.

In summary, any change in river-streamflow regime or sediment supply will cause adjustments in channel hydraulic characteristics, and changes in the variables of a river system will be such that hydraulic adjustment will be minimized (Langbein, 1964). At best, only general predictions can be made about the types of adjustments that will result from changes in hydrologic conditions. By the same reasoning, it is difficult to identify precise levels of reduced annual streamflow and anticipated sediment supply that will result in minimal alteration of a river reach from its existing character. Estimates of the sediment surplus or deficit at Deerlodge Park for several given streamflow frequency distributions, and various annual total sediment loads and annual sediment supplies from upstream are given in the sediment budget in table 6. The estimates are based on prevailing hydraulic conditions of slope, channel geometry, velocity distribution, stage-discharge relation, sediment discharge-water discharge relation, and sediment size. This table cannot be used to predict specific or local geomorphic responses if the system is thrown grossly out of balance, but it can be used as a management tool to identify possible changes in channel equilibrium resulting from reduced mean-annual streamflow or sediment supply. Other streamflow-duration curves, such as those based on streamflow requirements specified from biological studies, may be substituted in computations to estimate annual sediment loads. Likewise, sediment-supply scenarios may be adjusted as more specific information becomes available to identify the location and efficiency of potential sediment trap areas in the Yampa basin.

#### SUMMARY AND CONCLUSIONS

The physical and biological character of the Yampa River in Dinosaur National Monument primarily is controlled by the prevailing streamflow regime and transported sediment. Preserving the physical and biological environment of the Yampa River through Deerlodge Park and Yampa Canyon will require maintenance of a range of streamflows for a given sediment supply over a period of

years. Development of water resources in the Yampa River basin can affect the geomorphology, hydrology, and ecology of the river by changing the timing or magnitude of streamflow and by causing an imbalance in the sediment budget. A technique has been developed to estimate how the sediment load through Deerlodge Park and into Yampa Canyon immediately downstream would change in response to altered or reduced streamflow and sediment supply. This information, in turn, can be used to develop scenarios on how the Yampa River at Deerlodge Park and in Yampa Canyon might respond.

River stage was recorded and discharge was measured at a new streamflow-gaging station, 09260050 Yampa River at Deerlodge Park, during the 1982 and 1983 water years. Discharges recorded at this site correlated well ( $R^2=0.98$ ) with the sum of discharges recorded during the same period at two U.S. Geological Survey streamflow-gaging stations in the drainage basin upstream: 09251000 Yampa River near Maybell and 09260000 Little Snake River near Lily. The sum of historic discharges recorded at Maybell and Lily were used to estimate historic discharges at Deerlodge Park. The period 1941 through 1983 was used to estimate mean annual streamflow at Deerlodge Park. A streamflow-duration curve was derived from the combined record (fig. 6), and mean annual streamflow was determined to be 1.5 million acre feet per year.

Sediment data were collected at station 09260050 Yampa River at Deerlodge Park to compute the mean annual sediment load transported through Deerlodge Park and into the Yampa Canyon. Suspended-sediment discharges and bedload transport rates were measured 32 times throughout a range of water discharge during 1982 and 1983. Bed material as well as bedload in the Yampa River at Deerlodge Park predominantly consisted of medium to coarse sand; the median grain size was about 0.60 mm. Silt- and clay-size material constituted a large part of the suspended load, and averaged 40 percent of the total suspended-sediment load.

Daily sediment discharges were computed from instantaneous measurements according to standard U.S. Geological Survey procedures (Porterfield, 1972); in addition, they were estimated with the Modified Einstein procedure (Colby and Hembree, 1955) for comparison. Suspended-sediment discharge, bedload discharge, total sediment discharge and various size fractions of the total sediment discharge are presented as linear functions of water discharge in tables 3 and 4. As a test of the significance of seasonality in sediment discharge, a Student t-test was performed on slopes and intercepts of the measured transport rate relations; no differences were found at the 95-percent level that could be attributed to seasonality. Therefore, separate transport equations for rising and recessional discharge periods were not used.

Annual sediment loads were computed using the historic frequency distribution of streamflow and sediment transport equations based on both measured sediment discharges and sediment discharges estimated with the Modified Einstein procedure (Miller, 1951). Annual total sediment load based on measured sediment discharges was 2.04 million ton/yr, and annual total sediment load based on Modified Einstein procedure estimates of sediment discharges was 2.42 million ton/yr. Annual suspended sediment load was approximately 1.9 million ton/yr. Scour during high flows exposed bedrock at one part of the channel at the Deerlodge Park study site. Due to the nature of computations involved, this may have caused the Modified Einstein procedure to

overestimate the bedload equivalent part of total sediment discharge for some high-flow sediment discharge estimates. Subsequent annual sediment load computations and analyses utilized the sediment transport equations based on measured sediment discharges.

Flood discharges greater than 12,000 ft<sup>3</sup>/s scour the riverbanks and the riverbed, and cumulatively transport roughly one-fourth of the annual sediment load in the lower Yampa River (fig. 7). Reducing annual streamflow or altering the time and range of discharge peaks can affect sediment transport to varying degrees. Altering the duration of high and low discharges (fig. 8), while leaving mean annual volume of runoff unchanged can result in appreciable reductions in the mean annual sediment load. If the balance of sediment supply and transport is disrupted by a change either in local sediment transport or sediment supplied from upstream, a period of instability characterized by channel aggradation or degradation may result.

A sediment budget for the Yampa River at Deerlodge Park was developed using prevailing hydraulic conditions of slope, channel geometry, velocity distribution, stage-discharge relation, sediment discharge-water discharge relation, and sediment size distribution. The sediment budget provides estimates of annual sediment surpluses or deficits, given several combinations of streamflow frequency distribution, annual streamflow, and annual sediment supply. As a management tool, the sediment budget cannot predict the specific geomorphic response of the river system to changes in hydrologic variables. It does provide information on combinations of mean annual streamflow and mean annual sediment supply, for specified flow-frequency distributions, that could maintain a balanced sediment budget, thereby minimizing accompanying channel adjustments. Scenarios presented in this sediment budget analysis are hypothetical and are presented as an example of how the analysis may be used. Other streamflow-frequency distributions, mean annual streamflows, or mean annual sediment supplies may be substituted in computations to estimate mean sediment surpluses or deficits.

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**SUPPLEMENTAL DATA**



Table 7.--Hydraulic geometry and discharge data at station 09260050 Yampa River at Deerlodge Park

[ft<sup>3</sup>/s, cubic foot per second; ft/s, foot per second; ft, foot; ft<sup>2</sup>, square foot; °C, degree Celsius]

Sam- ple num- ber	Date	Time	Dis- charge (ft <sup>3</sup> /s)	Mean veloc- ity (ft/s)	Width (ft)	Area (ft <sup>2</sup> )	Mean depth (ft)	Temp- era- ture (°C)	Gage height (ft)	Slope (ft/ft)
1	4-01-82	1300	1,570	1.99	386	789	2.04	8.0	4.23	-----
2	4-27-82	1400	7,590	3.91	306	1,899	6.21	10.7	7.15	-----
3	5-12-82	1400	9,410	3.91	306	2,408	7.87	8.0	8.10	-----
4	5-13-82	1400	8,820	3.34	306	2,359	7.71	8.0	7.84	-----
5	5-24-82	1430	9,700	3.87	307	2,504	8.16	13.8	8.68	-----
6	5-25-82	1045	10,900	4.04	307	2,708	8.82	13.2	8.89	-----
7	6-08-82	1330	9,400	3.77	306	2,493	8.15	11.5	8.10	-----
8	6-24-82	1400	10,000	4.24	306	2,363	7.72	15.5	8.04	-----
9	6-25-82	1215	9,600	4.15	306	2,314	7.56	15.0	8.07	-----
10	7-07-82	1500	6,250	4.27	300	1,423	4.74	17.5	6.51	-----
11	7-08-82	1300	6,240	4.42	298	1,410	4.73	19.2	6.30	-----
12	7-29-82	1315	2,350	2.72	292	866	2.97	21.5	4.66	-----
13	2-23-83	1340	646	1.98	164	326	1.99	1.5	3.28	-----
14	3-10-83	1215	1,190	2.01	322	593	1.84	5.0	4.00	-----
15	3-15-83	1450	3,480	2.79	296	1,250	4.22	3.0	5.60	-----
16	3-29-83	1200	1,190	1.91	348	626	1.80	7.2	3.79	0.00080
17	4-07-83	1205	930	1.94	226	478	2.12	5.5	3.65	0.00072
18	4-08-83	1130	859	1.83	225	469	2.08	5.0	3.60	-----
19	4-19-83	1050	1,210	1.86	290	651	2.24	9.7	4.06	-----
20	4-21-83	1730	3,620	2.53	292	1,439	4.93	10.0	5.68	-----
21	4-22-83	1040	3,810	2.65	295	1,436	4.87	9.7	5.69	0.00047
22	5-07-83	1215	6,530	3.70	299	1,764	5.90	5.0	6.66	0.00071
23	5-09-83	1220	6,080	3.66	297	1,663	5.60	----	6.38	-----
24	5-12-83	1045	11,900	4.05	305	2,942	9.65	9.5	8.87	0.00085
25	5-23-83	1515	8,620	3.63	301	2,374	7.89	14.4	7.76	0.00060
26	5-26-83	1210	15,200	4.30	301	3,538	11.8	14.4	10.50	0.00087
27	5-27-83	1550	15,800	4.11	303	3,851	12.7	14.2	11.23	0.00078
28	5-28-83	955	17,600	4.32	303	4,074	13.4	12.5	11.61	-----
29	6-08-83	1350	14,400	4.33	303	3,317	11.0	11.7	11.21	0.00067
30	6-10-83	1200	15,000	4.38	297	3,419	11.5	12.8	11.43	0.00073
31	6-21-83	1450	15,800	4.33	300	3,645	12.2	16.4	12.45	0.00065
32	6-23-83	1210	15,700	4.03	300	3,881	12.9	15.8	12.50	-----
33	7-12-83	1355	7,180	3.38	302	2,122	7.03	20.0	7.84	0.00040
34	7-14-83	1125	5,540	2.96	298	1,871	6.28	21.1	6.99	-----
35	8-02-83	1425	2,130	2.60	288	818	2.84	22.2	5.30	-----

Table 8.--Suspended sediment size distribution at station 09260050 Yampa River at Deerlodge Park

[Percent finer than millimeters; all material is finer than 2.00 millimeters; mm, millimeter; mg/L, milligram per liter]

Sam- ple num- ber	1.00 mm (percent)	0.50 mm (percent)	0.25 mm (percent)	0.125 mm (percent)	0.062 mm (percent)	Concentra- tion (mg/L)
1	----	---	---	---	---	457
2	100	94	85	74	65	3,020
3	98	80	48	30	23	1,840
4	100	84	68	52	39	970
5	100	100	92	74	59	1,020
6	100	100	96	80	63	1,020
7	100	84	43	27	20	1,040
8	100	97	76	64	48	340
9	100	80	28	23	17	939
10	100	97	80	62	45	283
11	94	19	12	9	8	1,200
12	100	96	94	90	84	706
13	99	96	83	61	53	137
14	100	100	98	96	94	834
15	99	91	83	76	71	5,600
16	100	99	97	92	89	287
17	100	88	70	66	65	579
18	100	100	99	95	92	322
19	100	100	96	91	88	855
20	100	88	79	73	66	2,480
21	100	100	95	89	81	2,620
22	100	96	87	80	70	1,400
23	100	98	91	82	71	812
24	100	89	82	77	65	2,900
25	100	100	96	90	80	1,480
26	100	100	98	95	82	2,320
27	100	100	98	95	80	2,060
28	100	97	92	87	73	2,020
29	100	99	94	79	65	1,030
30	100	99	93	80	66	819
31	100	97	86	76	63	634
32	100	98	93	82	66	552
33	100	81	52	33	25	559
34	100	100	83	61	47	382
35	---	---	--	--	--	-----

Table 9.--Bed material size distribution at station 09260050 Yampa River at Deerlodge Park

[Percent finer than millimeters; all material is finer than 32.00 millimeters; mm, millimeter; mg/L, milligram per liter]

Sam- ple num- ber	16.00 mm (per- cent)	8.00 mm (per- cent)	4.00 mm (per- cent)	2.00 mm (per- cent)	1.00 mm (per- cent)	0.50 mm (per- cent)	0.25 mm (per- cent)	0.125 mm (per- cent)	0.062 mm (per- cent)
1	97	95	93	90	80	50	7	1	0
2	100	99	98	83	40	9	1	1	0
3	97	94	91	88	78	36	3	0	0
4	100	99	98	97	85	46	6	0	0
5	100	100	99	96	90	74	18	1	0
6	96	96	95	94	89	74	22	2	0
7	100	100	100	98	91	56	8	1	0
8	100	99	97	92	77	38	3	0	0
9	---	---	---	--	--	--	--	-	-
10	100	97	89	75	52	16	1	0	0
11	99	97	91	78	50	11	1	0	0
12	100	99	96	89	69	26	5	0	0
13	100	99	98	94	81	40	6	0	0
14	100	100	99	97	87	51	8	1	0
15	100	100	97	92	74	34	7	1	0
16	100	100	98	95	82	30	3	0	0
17	100	100	98	93	76	40	8	0	0
18	100	99	98	94	82	46	10	0	0
19	100	100	98	94	80	40	5	0	0
20	100	100	100	99	94	53	10	2	0
21	100	100	98	96	87	49	15	2	0
22	100	99	95	89	76	29	2	0	0
23	100	100	99	97	88	42	3	0	0
24	100	99	98	95	76	26	3	1	0
25	98	95	93	89	78	54	8	1	0
26	100	97	93	89	84	57	6	1	0
27	100	100	99	98	91	36	5	1	0
28	100	98	95	91	80	30	6	1	0
29	100	100	99	97	91	56	15	1	0
30	99	98	98	97	90	55	18	1	0
31	100	100	99	99	92	41	7	0	0
32	100	100	99	98	89	42	6	0	0
33	100	99	98	95	78	32	9	3	0
34	100	99	99	96	86	38	12	4	0
35	100	100	96	86	61	11	1	0	0

Table 10.--Bedload size distribution at station 09260050 Yampa River at Deerlodge Park

[Percent finer than millimeters; all material is finer than 32.00 millimeters; mm, millimeter; mg/L, milligram per liter]

Sam- ple num- ber	16.00 mm (per- cent)	8.00 mm (per- cent)	4.00 mm (per- cent)	2.00 mm (per- cent)	1.00 mm (per- cent)	0.50 mm (per- cent)	0.25 mm (per- cent)	0.125 mm (per- cent)	0.062 mm (per- cent)
1	---	---	--	--	--	--	-	-	-
2	100	99	98	96	87	47	6	1	0
3	100	99	97	94	85	49	7	0	0
4	100	98	95	89	72	36	4	0	0
5	100	100	99	99	96	82	15	1	0
6	100	99	98	98	94	77	14	1	0
7	100	100	100	99	95	63	7	0	0
8	100	100	99	96	85	49	3	0	0
9	100	100	99	96	82	39	2	0	0
10	100	100	98	92	71	18	1	0	0
11	100	98	94	86	62	16	1	0	0
12	100	100	98	93	76	30	4	0	0
13	---	---	---	--	--	--	--	-	-
14	100	100	99	99	93	43	4	0	0
15	---	---	---	--	--	--	--	--	-
16	100	100	98	94	75	29	2	0	0
17	100	100	100	99	92	64	7	0	0
18	100	100	100	98	88	53	3	0	0
19	100	100	99	97	88	51	4	0	0
20	100	100	98	95	87	50	7	1	0
21	100	99	98	95	85	52	8	1	0
22	100	99	98	97	87	35	2	0	0
23	100	99	99	97	86	35	2	0	0
24	100	99	98	96	79	27	3	1	0
25	98	97	94	89	65	29	4	0	0
26	100	100	98	96	90	50	6	2	0
27	100	100	99	97	91	39	4	1	0
28	100	100	100	99	95	62	8	2	0
29	98	95	94	90	79	50	8	1	0
30	100	100	99	98	90	33	4	0	0
31	100	100	99	98	92	40	4	1	0
32	100	100	100	99	92	44	5	1	0
33	100	100	99	98	89	36	4	0	0
34	100	100	100	98	87	42	4	0	0
35	99	98	95	88	63	12	1	0	0

Table 11.--Hydraulic geometry, discharge data, and sediment size distribution at station 09260000 Little Snake River near Lily

[ft<sup>3</sup>/s, cubic foot per second; ft/s, foot per second; ft, foot; ft<sup>2</sup>, square foot; °C, degree Celsius; mm, millimeter; mg/L, milligram per liter]

HYDRAULIC GEOMETRY AND DISCHARGE DATA									
Sam- ple num- ber	Date	Time	Dis- charge (ft <sup>3</sup> /s)	Mean veloc- ity (ft/s)	Width (ft)	Area (ft <sup>2</sup> )	Mean depth (ft)	Temper- ature (°C)	Gage height (ft)
1	2-23-83	950	249	2.12	60	117	1.95	0.0	2.71
2	3-16-83	1130	1,210	----	---	---	----	2.0	3.54
3	4-06-83	1030	327	2.24	95	146	1.54	0.0	2.22
4	5-10-83	1100	3,420	5.01	98	683	6.97	12.2	4.65
5	5-25-83	1030	4,620	5.76	94	802	8.53	14.0	5.50
6	6-07-83	1020	5,210	5.97	102	873	8.56	14.2	5.73
7	6-24-83	1240	4,340	5.61	102	773	7.58	17.8	5.34
8	7-15-83	1110	937	3.19	99	294	2.97	17.8	3.02
9	8-04-83	1120	365	2.34	99	156	1.58	22.8	2.30

SUSPENDED SEDIMENT SIZE DISTRIBUTION  
[Percent finer than millimeters; all material is finer than 2.00 millimeters]

Sample number	1.00 mm (percent)	0.50 mm (percent)	0.25 mm (percent)	0.125 mm (percent)	0.062 mm (percent)	Concentra- tion (mg/L)
1	100	87	66	59	58	954
2	100	100	99	95	91	7,630
3	100	100	93	82	76	1,570
4	100	99	97	93	83	4,700
5	99	96	92	84	67	3,000
6	98	91	85	66	51	1,880
7	100	96	87	70	48	1,060
8	100	89	66	37	27	516
9	100	98	92	86	85	538

BED MATERIAL SIZE DISTRIBUTION  
[Percent finer than millimeters; all material is finer than 32.00 millimeters]

Sample number	16.00 mm (per- cent)	8.00 mm (per- cent)	4.00 mm (per- cent)	2.00 mm (per- cent)	1.00 mm (per- cent)	0.50 mm (per- cent)	0.25 mm (per- cent)	0.125 mm (per- cent)	0.062 mm (per- cent)
1	100	98	96	91	78	43	3	0	0
2	100	99	97	95	85	48	11	1	0
3	100	100	99	97	89	57	9	1	0
4	100	99	97	95	85	47	9	3	1
5	100	99	99	97	80	25	5	1	0
6	96	93	90	84	46	12	3	1	0
7	97	94	92	87	73	34	6	1	0
8	99	98	95	88	66	23	3	0	0
9	100	99	97	92	68	21	2	0	0

Table 12.--Hydraulic geometry, discharge data, and sediment size distribution at ungaged site, Yampa River at Canyon Entrance

[ft<sup>3</sup>/s, cubic foot per second; ft/s, foot per second; ft, foot; ft<sup>2</sup>, square foot; °C, degree Celsius; mm, millimeter; mg/L, milligram per liter]

HYDRAULIC GEOMETRY AND DISCHARGE DATA

Sample number	Date	Time	Discharge (ft <sup>3</sup> /s)	Mean velocity (ft/s)	Width (ft)	Area (ft <sup>2</sup> )	Mean depth (ft)	Temperature (°C)	Gage height (ft)	Slope (ft/ft)
1	4-20-83	1345	2,150	2.48	226	868	3.84	10.6	5.88	0.00060
2	4-21-83	1000	3,260	2.80	229	1,164	5.08	9.7	7.10	-----
3	5-08-83	1330	5,640	3.35	235	1,684	7.17	11.9	8.34	-----
4	5-11-83	1155	9,960	4.06	235	2,475	10.5	-----	11.50	-----
5	5-24-83	1410	9,430	3.98	244	2,370	9.71	14.2	11.14	.00078
6	6-09-83	920	13,200	4.01	239	3,295	13.8	12.8	13.48	.00033
7	6-22-83	1730	15,000	4.92	241	3,040	12.6	15.6	14.38	.00038
8	7-13-83	1405	5,390	3.51	227	1,535	6.76	17.8	8.06	.00055
9	8-03-83	1430	1,804	2.66	222	679	3.06	21.1	4.88	.00083

SUSPENDED SEDIMENT SIZE DISTRIBUTION

[Percent finer than millimeters; all material is finer than 2.00 millimeters]

Sample number	1.00 mm (percent)	0.50 mm (percent)	0.25 mm (percent)	0.125 mm (percent)	0.062 mm (percent)	Concentration (mg/L)
1	100	81	57	55	50	1,810
2	100	98	94	92	84	2,880
3	100	100	95	88	78	1,140
4	100	99	96	92	80	3,170
5	100	97	92	87	75	1,640
6	100	100	97	84	72	1,210
7	100	89	59	49	40	818
8	100	91	51	30	22	582
9	97	79	31	25	23	787

Table 12.--Hydraulic geometry, discharge data, and sediment size distribution at ungaged site, Yampa River at Canyon Entrance--Continued

BED MATERIAL SIZE DISTRIBUTION

[Percent finer than millimeters; all material is finer than 64.00 millimeters]

Sample number	16.00 mm (per-cent)	8.00 mm (per-cent)	4.00 mm (per-cent)	2.00 mm (per-cent)	1.00 mm (per-cent)	0.50 mm (per-cent)	0.25 mm (per-cent)	0.125 mm (per-cent)	0.062 mm (per-cent)
1	100	100	99	97	86	36	3	0	0
2	100	98	96	91	78	36	3	0	0
3	100	99	98	96	86	43	4	0	0
4	---	---	--	--	--	--	--	-	-
5	100	99	98	94	82	43	3	0	0
6	91	90	86	82	74	51	12	1	0
7	83	81	77	72	61	31	4	0	0
8	100	98	96	93	81	41	4	0	0
9	100	100	98	95	84	34	1	0	0

BEDLOAD SIZE DISTRIBUTION

[Percent finer than millimeters]

Sample number	16.00 mm (per-cent)	8.00 mm (per-cent)	4.00 mm (per-cent)	2.00 mm (per-cent)	1.00 mm (per-cent)	0.50 mm (per-cent)	0.25 mm (per-cent)	0.125 mm (per-cent)	0.062 mm (per-cent)
1	100	100	99	97	88	45	3	0	0
2	100	100	99	96	87	46	43	1	0
3	100	99	97	94	82	38	3	0	0
4	100	100	99	97	88	40	5	2	0
5	100	99	97	91	72	26	2	0	0
6	100	98	97	94	81	30	6	0	0
7	100	98	94	88	71	31	4	0	0
8	100	98	96	92	79	40	3	0	0
9	100	100	99	97	88	36	2	0	0

Table 13.--Measured sediment discharge by size at station 09260050 Yampa River at Deerlodge Park

[Tons per day; mm, millimeter]

Sample number	Dis-charge	Total load	Sus-pended load	Bed load	<.062 (mm)	0.062 -.125 (mm)	0.125 -0.25 (mm)	0.25 -0.5 (mm)	0.50 -1.0 (mm)	1.0 -2.0 (mm)	2.0 -4.0 (mm)	>4.0 (mm)
1	1,570	-----	-----	-----	-----	-----	-----	-----	-----	---	---	---
2	7,590	62,900	61,600	1,360	40,300	5,460	6,760	6,110	4,090	125	31	24
3	9,410	47,400	45,900	1,520	10,900	3,320	8,370	14,800	8,610	1,270	43	46
4	8,820	24,800	22,800	1,930	8,940	3,080	3,650	4,380	4,160	317	124	91
5	9,700	27,400	26,600	827	15,700	4,000	4,880	2,630	115	25	6	5
6	10,900	30,800	29,800	937	18,800	5,060	4,900	1,810	155	39	6	15
7	9,400	27,500	26,000	1,520	5,280	1,810	4,530	11,200	4,650	61	11	8
8	10,000	11,000	9,100	1,860	4,440	1,480	1,140	2,710	905	202	52	26
9	9,600	28,400	23,700	4,740	4,210	1,340	1,400	13,900	6,660	663	142	57
10	6,250	6,930	4,730	2,200	2,170	809	870	1,120	1,330	466	119	51
11	6,240	21,100	19,300	1,750	1,510	384	696	1,450	15,300	1,470	142	101
12	2,350	5,360	4,460	897	3,770	243	223	351	535	270	48	18
13	646	-----	234	-----	-----	-----	-----	-----	-----	-----	-----	-----
14	1,190	2,800	2,680	121	2,510	75	63	72	70	7	1	1
15	3,480	-----	52,000	-----	-----	-----	-----	-----	-----	-----	-----	-----
16	1,190	1,060	917	140	820	32	40	56	73	27	6	2
17	930	1,460	1,400	53	946	19	49	272	166	3	1	0
18	859	818	746	72	684	23	33	43	27	7	1	0
19	1,210	3,400	2,780	621	2,460	79	164	392	233	57	14	5
20	3,620	24,200	23,900	350	15,900	1,860	1,280	2,330	2,800	28	12	7
21	3,810	27,200	26,800	343	21,800	2,100	1,580	1,440	166	34	8	8
22	6,530	25,700	24,500	1,160	17,300	2,500	1,750	2,510	1,490	112	22	17
23	6,080	15,000	13,300	1,690	9,490	1,500	1,150	1,500	1,090	180	32	17
24	11,900	93,800	92,500	1,270	60,200	11,400	4,310	6,800	10,600	475	35	22
25	8,620	35,100	34,500	1,070	27,600	3,490	2,180	1,500	379	257	60	60
26	15,200	96,000	95,000	988	78,200	12,400	3,080	1,830	392	65	18	18
27	15,800	88,600	87,600	928	69,900	13,200	3,180	1,690	490	56	14	10
28	17,600	97,100	96,100	992	70,600	12,900	5,170	4,770	3,540	37	7	4
29	14,400	40,700	39,900	805	22,000	4,650	4,330	2,090	529	44	8	4
30	15,000	33,600	33,100	536	26,000	5,560	5,970	2,480	510	89	26	52
31	15,800	28,200	27,000	1,260	16,900	3,690	2,590	3,380	1,530	78	10	13
32	15,700	24,000	23,400	634	15,400	3,720	2,740	1,400	670	42	4	2
33	7,180	11,500	10,600	882	2,730	805	2,120	3,300	2,460	76	10	8
34	5,540	6,430	5,570	761	2,680	785	1,300	1,220	345	33	12	3
35	2,130	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----



Table 14.--Estimated sediment discharge by size computed with the Modified Einstein procedure at station 09260050 Yampa River at Deerlodge Park

[Tons per day; mm, millimeter]

Sample number	Dis-charge	Total load	<.062 (mm)	0.062 -.125 (mm)	0.125 -0.25 (mm)	0.25 -0.5 (mm)	0.50 -1.0 (mm)	1.0 -2.0 (mm)	2.0 -4.0 (mm)	>4.0 (mm)
1	1,570	-----	-----	-----	-----	-----	-----	-----	-----	---
2	7,590	73,100	40,400	5,570	7,130	6,880	5,340	6,370	1,480	18
3	9,410	54,400	11,000	3,390	8,850	18,000	11,400	1,730	110	8
4	8,820	26,400	8,950	3,170	4,040	6,030	3,580	622	19	0
5	9,700	32,000	15,700	4,200	5,880	4,930	1,030	237	20	0
6	10,900	35,100	18,800	5,340	6,140	3,730	920	160	16	0
7	9,400	32,700	5,280	1,860	4,890	14,600	5,510	543	18	0
8	10,000	15,000	4,450	1,550	1,290	3,670	2,710	1,210	134	10
9	9,600	36,500	4,220	1,380	1,440	16,400	9,950	2,870	215	12
10	6,250	9,650	2,170	858	1,080	1,770	1,300	1,510	824	138
11	6,240	41,300	1,510	390	557	1,650	20,100	13,500	3,340	282
12	2,350	5,290	3,780	259	239	222	470	308	17	0
13	646	336	126	21	67	62	50	10	0	0
14	1,190	2,890	2,520	84	86	106	80	11	0	0
15	3,480	56,000	37,200	3,110	3,570	4,750	5,680	1,650	36	0
16	1,190	1,030	824	35	48	44	63	19	0	0
17	930	1,720	949	20	51	366	275	58	0	0
18	859	834	686	25	42	44	33	4	0	0
19	1,210	3,010	2,460	82	165	161	123	20	0	0
20	3,620	25,200	15,900	1,920	1,390	3,040	2,860	55	0	0
21	3,810	29,300	21,800	2,180	1,780	2,060	1,300	103	2	0
22	6,530	29,000	17,300	2,580	1,950	3,410	2,790	888	86	4
23	6,080	16,400	9,510	1,560	1,340	2,120	1,490	316	19	0
24	11,900	104,000	60,200	11,500	4,520	7,870	14,900	4,540	141	3
25	8,620	38,100	27,700	3,670	2,610	2,740	1,020	346	30	1
26	15,200	104,000	78,300	12,800	3,500	6,590	2,050	319	75	9
27	15,800	7,900	69,900	13,600	3,470	5,420	4,960	540	26	1
28	17,600	103,000	70,700	13,200	5,490	5,660	6,800	1,350	114	15
29	14,400	46,300	26,100	5,770	6,980	4,530	2,530	348	27	2
30	15,000	39,200	22,000	4,820	5,120	4,160	2,680	411	21	1
31	15,800	32,900	17,000	3,800	2,900	5,020	3,700	500	12	1
32	15,700	27,200	15,400	3,860	3,180	2,320	2,060	365	16	1
33	7,180	15,300	2,730	828	2,320	4,170	3,950	1,240	32	0
34	5,540	8,330	2,680	818	1,460	1,470	1,670	218	6	0
35	2,130	-----	-----	-----	-----	-----	-----	-----	-----	---